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**The Opening Address at the ATRS 2003 Conference, Toulouse, France**

By
**Professor Tae Hoon Oum,**
President, Air Transport Research Society, and
UPS Foundation Chair in Transport and Logistics,
University of British Columbia, Canada
July 11, 2003

Distinguished guests, ladies and gentlemen! It gives me a great pleasure to welcome all of you to the ATRS World Conference being hosted jointly by Groupe ESC (Toulouse Business School) and the ENAC (Ecole Nationale de Aviation Civile).

Today and tomorrow, in addition to the Opening and the Closing Plenary sessions, 112 papers will be presented on virtually all aspects of air transport and related topics.

2003 is a particularly challenging year to air transport policy makers, aviation executives and researchers as most of the major network airlines are experiencing unprecedented level of financial difficulties in the 100-year history of aviation. But I am reminded of Mr. Georges Clemencau, the French Leader during the first World War. He said "our country advances ONLY through crisis and in tragedy". Likewise, I am confident to predict that air transport industry will also advance through these crises. Airlines are succeeding in restructuring their service networks, and streamlining their operations to an unprecedented level, and start to listen to what their customers and markets are telling them more closely. Most major network carriers in the United States and Canada have achieved a unit cost reduction of about 25% via their recent restructuring efforts. They will be coming out of these crises with resounding success in order to serve the rising demands for efficient and cost effective services. Now, I believe it is turn for the airports and air traffic control systems to do a restructuring comparable to what airlines have been doing in recent years. In this regard, I am particularly happy to see many papers and presentations in this conference are focusing the airports and air traffic control systems.

As a final note, on behalf of the ATRS, I would like to express sincere appreciation to Mr. Herve Passeron, Director of Groupe ESC-Toulouse, and Mr. Gérard Rozenknop, Director of the ENAC, and above all, Professor Sveinn Gudmundsson for their tremendous efforts to organize this conference so successfully. I also like to express our appreciation to AirBus Industries, City of Toulouse, Toulouse Chamber of Commerce, Aeroport Toulouse-Blagnac, and EQUIS for their active participation in this program and for their financial supports.

I look forward to a stimulating conference in the next couple of days.
Thank you very much.

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# THE TEMPORAL CONFIGURATION OF EUROPEAN AIRLINE NETWORKS

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## Abstract

The deregulation of US aviation in 1978 resulted in the reconfiguration of airline networks into hub-and-spoke systems, spatially concentrated around a small number of central airports or 'hubs' through which an airline operates a number of daily waves of flights. A hub-and-spoke network requires a concentration of traffic in both space and time.

In contrast to the U.S. airlines, European airlines had entered the phase of spatial network concentration long before deregulation. Bilateral negotiation of traffic rights between governments forced European airlines to focus their networks spatially on small number of 'national' airports. In general, these star-shaped networks were not co-ordinated in time. Transfer opportunities at central airports were mostly created 'by accident'.

With the deregulation of the EU air transport market from 1988 on, a second phase of airline network concentration started. European airlines concentrated their networks in time by adopting or intensifying wave-system structures in their flight schedules. Temporal concentration may increase the competitive position of the network in a deregulated market because of certain cost and demand advantages.

This paper investigates to what extent a temporal concentration trend can be observed in the European aviation network after deregulation. We will analyze the presence and configuration of wave-system structures at European airline hubs as well as the resulting transfer opportunities. We use OAG data for all European carriers with scheduled services between 1990 and 1999.

We conclude that a temporal concentration trend exists among European airlines. European deregulation has resulted in the adoption or intensification of wave-system structures by airlines. These wave-system structures as well as the overall traffic growth have significantly stimulated the number of indirect hub connections. Airline hubs with wave-system structures perform generally better than airline hubs without a wave-system structure in terms of indirect connectivity given a certain number of direct connections.

**Keywords:** airline networks, wave-system structure, Europe, connectivity

## 1. INTRODUCTION

The European aviation market has gradually been deregulated by means of three 'packages' of deregulation measures (1987, 1990, 1992) (Button *et al.*, 1998; Hakfoort, 1999). As a result of deregulation, the balance of power in the European air transport regime has shifted from the governments towards the European airlines. Supported by the Common European Market and experiences with deregulation of the US aviation market, deregulation forced the EU Member states to reduce their strong involvement with respect to the economic regulation of the European carriers with respect to intra-European air services.

After the deregulation of the aviation market in the United States in 1978, airlines took advantage of the possibilities of the liberalised market and reorganised their networks. A number of 'trunkline'-carriers reorganised their networks from 'point-to point' into 'hub-and-spoke' networks (Reynolds-Feighan, 1998, 2000; Viscusi et al., 1998). This reorganisation took place between 1978 and 1985, according to Reynolds-Feighan (2001). Direct flights from medium airports to other medium airports were increasingly replaced by indirect flights via a central airports or 'hubs'.

Spatial concentration and temporal concentration are the two main features of the hub-and-spoke network (Reynolds-Feighan, 2001). The hubbing carrier concentrates its network spatially around one or a small number of hubs. Regarding temporal concentration, the airline operates synchronized, daily waves of flights through these hubs (Graham, 1995; Reynolds-Feighan, 2000). The aim of such a wave-system structure is to optimise the number and quality of connections offered by an airline. The flight schedule optimisation through wave-system structures and spatial concentration can result in certain demand and cost side advantages as well as entry deterrence. The advantages of these hub-and-spoke systems have been extensively discussed elsewhere (see e.g. Button, 2002; Hanlon, 1996; Pels, 2001).

On the other hand, some new and incumbent U.S. airlines continued operating 'point-to-point' networks on a low-cost, no-frill, low-price basis. Low-cost carriers do not need the cost advantages of hub-and-spoke networks because they have low marginal costs per passenger. This is mainly the result of operating high density routes with high utilization rates, high density seating, standardization of aircraft types and maintenance, electronic ticketing, low levels of on-board service, use of under-utilized secondary airports and flexible labor contracts (Dempsey & Gesell, 1997; Doganis, 2001; Reynolds-Feighan, 2001; Williams, 2001).

In contrast to the large amount of empirical studies regarding the changes in airline network structures in the deregulated US air transport market, the number of empirical studies with respect to changing airline network configurations in Europe is rather limited. More knowledge of airline network behaviour in a deregulated European aviation regime is important from a societal perspective because of a number of reasons.

- The structure of airline networks affects airport planning and development including peaking problems at airports, uncertainty in airport traffic forecasting, runway construction plans, terminal lay-outs and regional accessibility (de Neufville, 1995).

- It can be expected that the effects of deregulation on the European airline network configurations will be different from the U.S. aviation network since the geographical, political and historical context is quite different from the European context (see also Bootsma, 1997; Burghouwt & Hakfoort, 2001).

From a scientific point of view, this study adds to the current body of knowledge because:

- This paper tries to reduce the apparent gap in the literature. Most studies take the airport-level as the object of analysis and do not analyze changes in network structures over time at the airline level (for an overview of studies see Burghouwt & Hakfoort, 2001).
- Most existing theoretical studies on airline network economics in a deregulated market use a network dichotomy. Generally, two different networks are considered as a starting point for analyses: the minimally connected network and the fully connected network (see e.g. Berechman & De Wit, 1996). In reality these two extreme network structures rarely exist (Pels, 2000, p. 70). The scale from full hub-and-spoke networks to fully connected (point-to-point) is continuous (Bootsma, 1997, p.4). By focusing on the spatial and temporal organisation of traffic flows insight into the usefulness of these economic models and their application to the European air transport system can be given.
- Most studies consider airline networks that are radially organized in space as an equivalent for hub-and-spoke networks (e.g. Bania et al., 1998; Burghouwt & Hakfoort, 2001; Goetz & Sutton, 1997; de Wit et al., 1999). However, a radial network is not an equivalent for a hub and spoke network as long as timetable coordination is lacking. Hence, this paper acknowledges both the spatial and temporal dimension to define airline networks.

This paper adds to the evidence by *providing an analysis of the changes in temporal dimension of airline network configurations in Europe between 1990 and 1999*[1].
The paper is structured as follows. Section 2 discusses previous studies and the theoretical background of the paper. In section 3, we describe the methodology of the weighted indirect connectivity index and the wave-structure analysis. Section 4 describes briefly the OAG data used in this paper. Section 5 and 6 discuss the empirical results regarding temporal concentration in the networks of the airlines. Section 7 concludes, discusses the policy implications of the results and indicates themes for further research.

## 2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

### 2.1 Theoretical considerations on the temporal configuration of an airline network

[1] This paper will not cover the spatial configuration of airline networks. We refer to Burghouwt et al. (2003) for an empirical analysis of the spatial dimension of airline networks in Europe based on the network concentration index.

Temporal concentration and spatial concentration are the two main features of the hub-and-spoke network (Reynolds-Feighan, 2001). Therefore, we define an airline network configuration as the spatial and temporal configuration of the network. The spatial configuration can be defined as the level of concentration of an airline network around one or a few central hub airports. This definition has been used to analyse the geographical structure of airline networks in Europe between 1990 and 1999 (Burghouwt et al., 2003).

Following the thesis of Bootsma (1997) on airline flight schedule development, we define the temporal configuration as the number and quality of indirect connections offered by an airline or alliance by adopting a wave-system structure in the airline flight schedule.

A wave-system structure consists of the number of waves, the timing of the waves and the structure of the individual waves. According to Bootsma (1997, p.53) a connection wave is 'a complex of incoming and outgoing flights, structured such that all incoming flights connect to all outgoing flights [..]'.

Three elements determine the structure of such a connection wave:
1. The minimum connection time for continental and intercontinental flights
2. The maximum connection times
3. The maximum number of flights that can be scheduled per time period

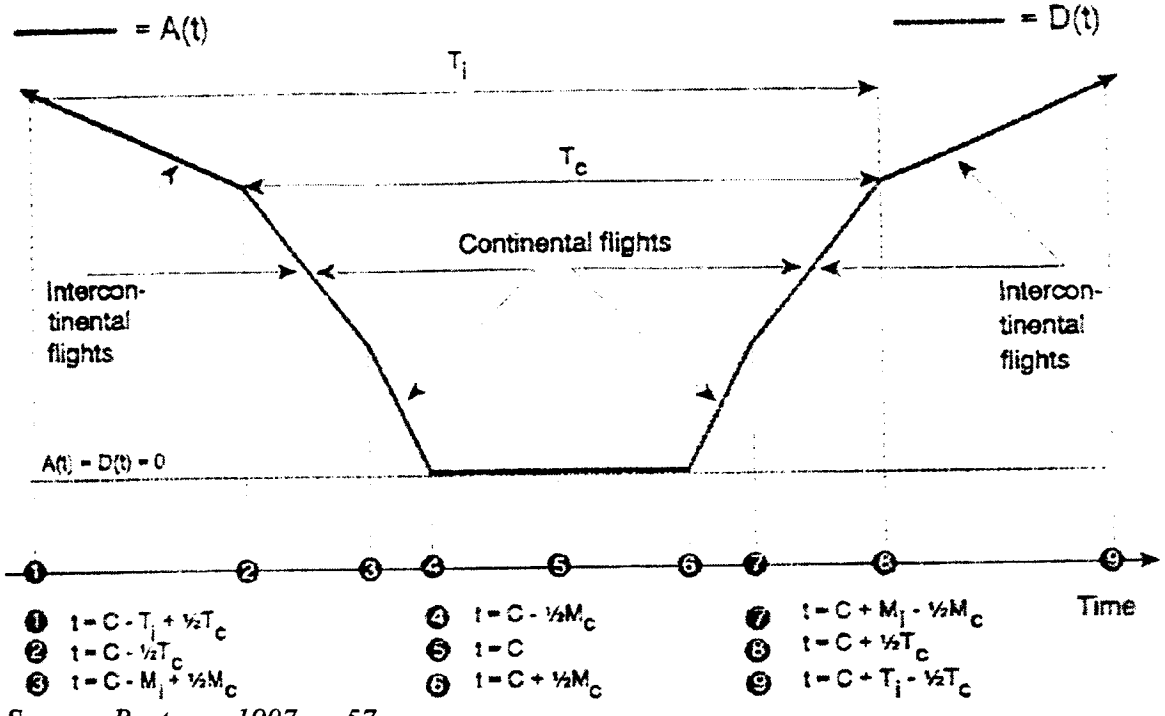
Figure 1 presents an ideal type of connection wave for a European hinterland hub. Connections have to meet the minimum connecting times (M). Then, a trade-off has to be made between the maximum acceptable connection time (T) for the airline and the maximum number of flights that can be scheduled in a time period (A(t)+D(t)). The hub-and-spoke concept favours adding a connection to the same wave. Since no airport has unlimited peak capacity however, adding new flights to the edges of the waves involves long waiting times which may not be acceptable for transfer passengers (Dennis, 2001).

However, in reality, such an ideal picture is not very likely to exist. Bootsma (1997) mentions the following disturbing factors:

- Some spokes may be located to close or to far away from the hub to fit in the wave-system structure. These flights will be located off-wave.
- Strict scheduling may jeopardize fleet utilization.
- Environmental constraints and/or capacity constraints may be an obstacle for airlines to fit all flights into the wave-system.
- In strong O-D markets, it may be attractive to schedule a number of flights off-wave.
- The incoming and outgoing European wave can overlap because not all connection are feasible because of the detour/routing factor
- We can add to this list the fact that an airline may simply not have chosen to adopt or may not be capable of adopting a wave-system structure

*Figure 1 Structure of the theoretical connection wave of a European hinterland hub.*

*A(t)=number of flights that still have to arrive at the hub at time t; D(t)= number of flights that still have to depart from the hub at time t; C=wave centre; $M_i$=minimum connection time for intercontinental flights; $M_c$= minimum connection time for continental flights; $T_i$=maximum connection time for intercontinental flights; $T_c$= maximum connection time for continental flights.*


= A(t)
= D(t)
$T_i$
$T_c$
Continental flights
Intercon-tinental flights
Intercon-tinental flights
A(t) = D(t) = 0
1 t = C - $T_i$ + ½$T_c$
2 t = C - ½$T_c$
3 t = C - $M_i$ + ½$M_c$
4 t = C - ½$M_c$
5 t = C
6 t = C + ½$M_c$
7 t = C + $M_i$ - ½$M_c$
8 t = C + ½$T_c$
9 t = C + $T_i$ - ½$T_c$
Time

*Source: Bootsma, 1997, p. 57*

Bootsma (1997) makes a clear distinction between the actual temporal configuration of the airline flight schedule (the wave-system structure) on the one hand and the effects of the airline flight schedule on the number and quality of the indirect connections generated by the flight schedule (indirect connectivity) on the other hand.

The resulting indirect connectivity of an airline hub will depend on a number of elements in the airline flight schedule (Bootsma, 1997; Dennis, 1998; Rand Europe; Veldhuis, 1997). Firstly, the number of direct flights (frequency) from and to the hub determines the maximum number of indirect connections following the formula n(n-1)/2, where n denotes the number of spoke-airports in the network.
Secondly, the number of indirect flights will depend on the minimum connection time at the airline hub (mct). The mct-window is required to allow passengers and baggage to transfer between two flights as well as to turn around the aircraft itself. Indirect connections not meeting the mct-criterion cannot be considered as a viable connection.

However, not every connection will be as attractive. An indirect flight with a waiting time of five hours will not be as attractive as the same indirect flight but with a transfer time of only 45 minutes.
Attractivity of an indirect connection depends on (Veldhuis, 1997):

- Waiting time at the hub: attractivity declines when waiting time increases.
- Routing factor: the in-flight time for an indirect flight compared to the direct-flight time. Some indirect connections (such as Hamburg-Oslo-Nice) are not attractive for the average air traveller because the detour factor is too large.
- Perception: passengers perceive transfer time longer than in-flight time (Veldhuis, 1997).
- Fares: lower fares may compensate for longer transfer and in-flight times.
- Flights of a certain airline may be attractive because the air traveller participates in the loyalty programme of the airline.
- Amenities of the hub-airport involved in the transfer.

When quantifying the effects of the configuration of the airline flight schedule in terms of indirect connectivity, one should take into account the difference in attractivity of a certain connection. However, since data on fares, airport quality and loyalty programmes are very scarce and unreliable, we will concentrate on the role of waiting time and flight time in this paper (see also Veldhuis, 1997).

Based on these theoretical considerations, we will use the characteristics of the ideal type connection wave as the benchmark for our analysis. We will:

1. Evaluate the indirect connectivity of the airline flight schedule given the presence or absence of a wave-system structure. We define indirect connectivity as the number and efficiency of the indirect connections generated by the existing flight schedule.
2. Analyse the presence of a wave-system structure empirically as well as the determination of the number of waves at the airline hub, based on the definition of a theoretical connection wave.
3. Assess the effects of the presence of a wave-system structure on the indirect connectivity.

However, we will first review existing literature to identify the scientific relevance of our research as well as the methodology used.

### 2.2 Literature review

A substantial amount of theoretical and empirical research has been carried out on airline network configurations. Most of these studies on airline network configurations focus on the spatial dimension of airline networks. The hub-and-spoke network is generally seen as a spatially concentrated network or minimally connected network. In the hub-and-spoke network, routes are deliberately concentrated on a few key nodes in the network. However, as we stated before, an airline network needs both spatial and temporal concentration of flights to qualify as a hub-and-spoke network.

Table 1 provides an overview of hub-and-spoke definitions of various authors to support the argument of the definition-bias. Besides, most of the studies have a very limited geographical scope. In the case of Europe, only the largest airlines and airports are considered in these studies.

*Table 1 Definition of the hub-and-spoke network according to various studies*

| Study | Definition | Level | Spatial/ | Type of |
|---|---|---|---|---|

| | | | **temporal concentration** | **study** |
|---|---|---|---|---|
| Bania, Bauer & Zlatoper, 1998, p.53 | [..] a hub-and-spoke network has most flights coming to a 'hub' airport from 'rim' airports, concentrating airline activity at a few locations. Travel between two rim airports involves flying first to the hub and then on to the final destination. | Airline level | Spatial and temporal concentration | Empirical, United States |
| Berry, Carnall & Spiller (1996), p.1 | '[In Hub-and-spoke networks], passengers change planes at a hub airport on the way to their eventual destination | Airline level | Spatial concentration | - |
| Bootsma, 1997, p.4 | [..] in case of hub-and-spoke, the network is designed as such, that routes are deliberately concentrated at a limited number of connection facilities called *hubs*. Destinations from each of these hubs are called spokes. [..]. In order to maximize these connection possibilities, the hub-carrier usually schedules its flights in a limited number of time-windows. | Airline level | Spatial and temporal concentration | Empirical, Europe major hubs |
| Burghouwt & Hakfoort, 2001, p. 311 | HS-network entail the combination of point-to-point with transfer traffic at a central hub | Airline level, but analysis takes place at the airport level | Spatial concentration | Empirical, all European airports |
| Button, 1998, p.20 | In hub-and-spoke operations, [..] carriers generally use one or more large airports [..]. Flights are arranged in banks which allow passengers continuing on to be consolidated on outbound flights to further destinations' | Airline level | Spatial and temporal concentration | - |
| Button, 2002, p. 177 | Airline networks that entail consolidating of traffic from a diverse range of origins and are destined to a diverse range of final destinations at large, hub airports | Airline level | Spatial concentration | - |
| Dempsey & Gesell (1997, p. 200) | Consolidation of operations around hubs by airlines | Airline level | Spatial concentration | - |
| Dennis (1998, p.2) | [Airline HS networks aim] 'to carry connecting passengers with both origin and destination outside their home country' | Analysis at airline level | Spatial and temporal concentration | Empirical, Europe's major hubs |
| Goetz & Sutton, 1997 | Major connection complexes for airlines | Airline level but analysis at airport level | Spatial concentration | Empirical, U.S. airport system |
| O'Kelly & | 'Hubs [..] are special nodes that are part of | Airport | Spatial | Theoretical |

| | | | | |
|---|---|---|---|---|
| Bryan (1998) | a network, located in such a way as to facilitate connectivity between interacting places' | level | concentration | |
| Oum, Zhang and Zhang (1995, p. 837) | Hub-and-spoke networks concentrate most of an airline's operations at one, or a very few, hub cities. Virtually all other cities in the network are served by non-stop flights from these hubs' | Airline level | Spatial concentration | Theoretical |
| Pels, 2000, p. 13 | In a HS-network, the hub airport is the only airport with a direct connection to all other airports. All passengers travelling between two 'spoke airports' (an indirect market) are channelled through the hub airport. The market between a hub and spoke is a spoke market | Airline level | Spatial concentration | Theoretical |
| Rietveld &Brons, 2001 | Hub-and-spoke networks enable carriers to supply transport services to many combinations of origins and destinations at high frequencies and low costs. | Airline level | Spatial concentration and temporal concentration | Empirical, Europe's 'big 4' |
| Veldhuis & Kroes, 2002 | Hub airports consider the *indirect* connections via their hub of essential strategic importance | Airport/ airline level | Spatial and temporal concentration in analysis | Empirical, Europe's major hubs |

Thus, only a small number of empirical studies has been carried out to measure temporal concentration of airline networks. Let us briefly discuss the methodology and results of the studies dealing with temporal concentration. We will then present an alternative to the existing methodologies.

*Bania, Bauer & Zlatoper (1998)*

Bania et al. provide a methodology for measuring the extent to which airlines operate hub-and-spoke networks. They take into account the spatial concentration of the network using the McShan-Windle index. Moreover, they take into account the possibility of making transfers from one flight to another at the hub airports. However, they consider every possible indirect connection as a viable connection, regardless of transfer time and routing factor. As we have seen, transfer time at the hub and routing factor are essential elements for the efficiency of the hub-and-spoke system. Therefore, we reject the Bania-methodology because of theoretical considerations.

*Dennis (1998)*

In his paper dealing with the competitive position of the main European hub airports, Dennis distinguishes three factors that determine the success of a hub airport: markets served, geographical location and transfer times/ schedule coordination.

Firstly, independent from location and transfer times, the number of flights on two origin-destination pairs served determines the number of indirect connections in comparison to other hubs. Dennis defines the hub potential as the share of the product of the frequency on the first and second leg of an indirect trip in a certain market at a certain airport in the sum of this product for all airports. He concludes that London Heathrow, Frankfurt and Paris Charles de Gaulle have the highest hub potential.

Secondly, the geographical location is important. Dennis studies this aspect by computing the total number of passenger kilometres necessary to connect every hub with all other hubs in the system. Brussels is most centrally located in Europe, even corrected for passenger numbers. Peripheral hubs Athens, Lisbon and Helsinki are worst located in terms of total passenger kilometres necessary to connect all the hubs.
Thirdly, having a good hub potential and geographical location would be sufficient to operate a successful hub. However, passengers are not prepared to wait an infinite time. Hence, transfers require the concentration of flight activity into a limited number of peaks or waves during the day in order to minimize waiting time. Dennis calculated the performance of the hubbing airline in generating an effective wave structure by computing the number of connections possible for each airline at each hub between the minimum connecting times and six hours as well as looking at the wave structure graphically. In 1998, Lufthansa at Frankfurt, Air France at Paris CDG and KLM at Amsterdam scored best.
The methodology of Dennis works well in getting a first impression of an airline hub, but does not result in insight into the level of timetable co-ordination since the effects of waiting time on the quality of a connection are not taken into account.

*Rietveld & Brons (2001)*
Rietveld & Brons (2001) state that waiting time at a hub airport is dependent on three factors: frequency, the minimal connection time (mct) and the time table co-ordination by the hub carrier. Knowing the mct values for a certain connection, the frequency for the flights concerned and the waiting time for that connection, the level of timetable co-ordination can be derived. From the total number of operating hours per day and the frequency on the most frequent leg of the connection ($F_2$), an expected average waiting time can be computed ($T_h$). The deviation from the real waiting time minus the mct is called alfa.

$$t_h = mct + g\frac{T}{F_2} \qquad (1)$$

$$\alpha = 1 - g \qquad (2)$$

The basic problem of the approach is the fact that the study assumes that the observed frequency on the route is one of the determinants for the waiting time at the hub. This seems to be a right conclusion: average waiting time decreases as frequency decreases. However, frequency is not the factor decisive for the waiting time ($T_h$) at the hub. It is the other way around: waiting time is decisive for the frequency. Airlines choose frequency based on O-D demand and transfer demand. Both determine the wave-system structure (time table coordination) including the number of waves (Bootsma, 1997). Ideally, every destination is being served in every wave. However, markets with very strong O-D demand may validate off-wave scheduling of these services. At the same time, connection with insufficient demand may result in connections not served in every wave. Without the time table coordination in the flight schedule/ wave structure, certain frequencies would not be possible because of lack of O-D demand. The Rietveld &

Brons-model has been based on the inaccurate assumptions creating a loop in the model. The model measures the level of timetable coordination based on frequency that is the result of the same timetable coordination because it assumes that frequency is only generated by O-D demand. However, as stated before, frequency is the result of both O-D and transfer demand which is partly the result of the wave-system structure adopted by the airline.

*Veldhuis, 1997*

Veldhuis (1997) uses the concept of connectivity units (cnu) to measure the competitive position of an airline or airport network. The frequency of a connection (direct or indirect), the non-stop travel time, perceived travel time, maximum perceived travel time and the transfer time are the inputs for the measure. The measure scales indirect travel time to the travel time of an indirect flight, making comparisons possible between indirect and direct connectivity.

The measure has been applied to various cases (see IATA, 2002; Veldhuis, 1997; Veldhuis, 2002; Veldhuis & Kroes, 2002) and has proved its usefulness. Drawback of the methodology is the fact that assumptions have to be made on the valuation of time by air passengers to make comparisons possible between indirect and direct connectivity.

We will use a somewhat simplified cnu-measure to assess the effects of the temporal configuration of an airline's network. It resembles to connectivity unit in weighing the number of frequency for the quality of the indirect connection. Our measure differs in the sense that we do not aim at comparing indirect and direct connectivity.

Yet, the cnu-methodology or a similar measure does only give insight in the consequences of a certain flight schedule on connectivity. Its basic handicap is the fact that such as measure does not give information about the structure of the flight schedule itself.

*Bootsma, 1997*

Bootsma uses the theoretical model of an ideal connection wave as the benchmark for the analysis of the wave-system structure and for the analysis of the effects of the wave-system structure on indirect connectivity (see also section 3.1 and 3.2). In contrast to the studies discussed above, it is important to notice that Bootsma distinguishes between the *description* of the temporal configuration of an airline network and the analysis of the *effects* of a certain temporal configuration on indirect connectivity. We will make the same distinction in this paper.

For the descriptive part of the analysis, Bootsma identifies the presence, timing and number of actual waves by identifying *local maxima* in the actual daily distribution of arriving and departing flights using the theoretical model of an ideal connection wave. This methodology will be discussed and adapted in section 3.1.

For the measurement of the indirect connectivity of an airline's flights schedule, he proposed a number of yardsticks, e.g. the number of indirect connections and the quality of those connections. One problem with the approach is the fact that the analysis of the quality of connections is very rough. A distinction is made between excellent, good and poor connections, based on waiting time at the hub. A continuous approach, such as the approach of Veldhuis (1997), might be more accurate. Moreover, Bootsma did not

consider the relevance of the connections, such as backtracking. Finally, the study considered only a few airline hubs empirically for the year 1994.

In summary, a small number of studies has analysed the temporal dimension of airline networks. These studies analyse the structure of the airline flight schedule itself (Bootsma, 1997; Dennis, 1998) or aim to assess the consequences of an actual flight schedule for the level of (in)direct connectivity (Bootsma, 1997; Veldhuis, 1997, 2002; Veldhuis & Kroes, 2002) or waiting time (Rietveld & Brons, 2001).
The methodology of Rietveld & Brons was rejected based on theoretical considerations. The methodology of Dennis works well getting a very first glance of the connectivity of an airline network or airport, but does not take into account the quality of an indirect connection.
Bootsma offers a very valuable methodology for describing the structure of an actual flight schedule. We will use a slightly adapted methodology to do the same. Both Bootsma and Veldhuis have developed a measure (cnx and cnu respectively) to analyse the effects of a certain flight schedule. We will use elements of both approaches for this study (see section 3).

## 3. METHODOLOGY

In section 2 we stated that this paper has a two-fold aim. Firstly, a description of the presence of a wave-system structure and the number of waves at an airline hub will be given. Secondly, an analysis of the effects of the wave-system structure on indirect connectivity will be performed. The first question can be answered using the theoretical wave-system structure developed by Bootsma (1997) (section 3.1). The second question will be answered using a simplified connectivity measure (section 3.2).

### 3.1 A methodology for the identification of the wave- system structure

Recalling figure 1 and Bootsma (1997, p.61), the time windows for departing and arriving intercontinental (ICA) and departing and arriving European (EUR) flights can be determined:

- ICA-arriving window: $[C-T_i+0.5T_c, C-M_i+0.5M_c]$ (3)
- ICA-departing window: $[C+M_i-0.5M_c, C+T_i-0.5T_c]$ (4)
- EUR-arriving window: $[C-0.5T_c, C-0.5M_c]$ (5)
- EUR-departing: $[C+0.5M_c, C+0.5T_c]$ (6)

Where:
$T_i$ is the maximum connecting time involving intercontinental flights;
$T_c$ is the maximum connecting time for connecting European flights;
$M_i$ is the minimum connecting time involving intercontinental flights;
$M_c$ is the minimum connecting time for connecting European flights;
C is the wave centre.

Bootsma (1997) has defined standard maximum connection times for different types of connections: the quality thresholds (see table 2). Minimum connection times are unique for every hub airport and can be derived from the Official Airline Guide (OAG). For the

sake of simplicity of the wave-structure analysis, we have chosen a minimum connection time of 40 minutes for all flights and a maximum connection time of 90 minutes for all flights for the analysis performed in section 6. The analysis shows that this choice does not influence the results significantly[2].

*Table 2 Connection quality thresholds (minutes) for different types of connections*

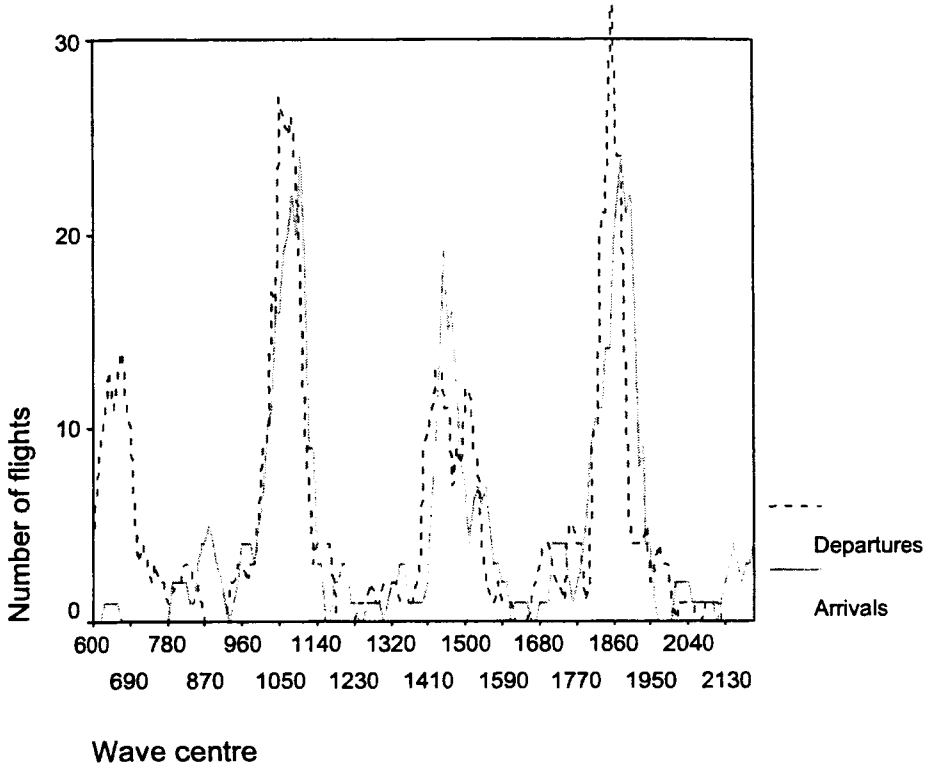
| Type of connection | $T_{excellent}$ | $T_{good}$ | $T_{poor}$ |
|---|---|---|---|
| EUR-EUR | 90 | 120 | 180 |
| EUR-ICA | 120 | 180 | 300 |
| ICA-ICA | 120 | 240 | 720 |

*Source: Bootsma, 1997, p.68*

Given the theoretical definition of an ideal connection wave, the actual wave-system structure can be identified. This can be done by creating artificial wave centres every x-minutes of the day. Whether an airline actually operates a wave structure at that time of the day for that wave-centre, is determined by counting the number of flights within the departure and arrival windows for the specific wave-centre.
We have illustrated the procedure for the network of Lufthansa at Munich (figure 2). We have created artificial wave centres every 6 minutes of the day. Maximum connection time is 90 minutes for all flights. Minimum connection time has been set on 40 minutes. Hence, flights have to arrive between t=C- 45 and t=C-20. Flights have to depart between t=C+20 and t=C+45 to fit into the artificial wave. A wave-centre of a wave can be identified when the wave-centres for incoming and outgoing flights coincide almost completely.
At Lufthansa's hub Munich, we can identify a clear wave-system structure with three connection waves: morning, afternoon and evening. The wave centres for departures and arrivals overlap. Local maxima differ significantly from the following local minima, resulting in a clear peak-pattern in the flight schedule.

[2] For the analysis performed in section 5 (see also section 3.2) unique minimum connection times for every airport have been applied.

*Figure 2 Wave-system analysis for Lufthansa at Munich, 1999*




*Source: OAG/ ABC*

The research of Bootsma shows that this methodology is a helpful approach for identification of the presence of a wave-system structure, the number of waves and the timing of the waves. The approach needs a numerical or graphical representation to capture the 'local maxima' (Bootsma, 1997, p. 60).
For a large number of airline hubs, identification of 'local maxima' per airline hub becomes very time-consuming. Therefore, we will first evaluate the effects of airline flight schedules on indirect connectivity (section 3.2). Only airline hubs with significant indirect connectivity will be analysed to identify the characteristics of the wave-system structure. Airports without significant indirect connectivity are not being considered as competitive hubs for the transfer market.

### 3.2 Evaluation airline flight schedule effects: indirect connectivity

For the purpose of this paper, we propose a combination of the Bootsma (1997)-methodology and the approach of Veldhuis (1997) for analysis of the indirect connectivity as the result of a certain airline flight schedule.
In section 2, we stated that the number of direct frequencies, the minimum connection times and the quality of the connection determine indirect connectivity.

Therefore, we have defined a weighted indirect connection[3] as:

$$WI = \frac{2.4 * TI + RI}{3.4} \tag{7}$$

where

$$TI = 1 - \frac{1}{T_j - M_{i,j}} Th \tag{8}$$

where Th>M
and
TI=0 when Th>T

$$RI = 1 - (2\frac{1}{2}R - 2\frac{1}{2}) \tag{9}$$

and

$$R = \frac{IDT}{DTT} \tag{10}$$

where
1<=R<=1.4
and
RI=0 when R>1.4

Where,
WI= weighted indirect connection
TI= transfer index
RI= routing index
Mi,j= minimum connection time for connection j at airport i
T= maximum connection time for connection j
Th= transfer time at the hub
IDT= actual in-flight time indirect connection
DTT= estimated in-flight time direct connection based on great circle distance
R= routing factor

The weighted connectivity of an indirect connection depends both on the quality of the connection at the hub (TI) as well as the quality of the indirect flight compared to the direct flight (RI). Both are defined as being a linear function of the flight time and transfer time respectively.

[3] Only intra-line, same day transfer connections (on a Wednesday) were considered in this paper. Future research should include transfer connections between flights of alliance partners

The transfer index (TI) equals 1 when the transfer time $T_h$ equals 0. The transfer index (TI) equals zero when the transfer time $T_h$ exceeds the maximum connection quality threshold $T_{poor}$ (table 2). We have not chosen to set the TI-index at 1 when $T_h$ equals the minimum connection time in order to include differences in minimum connection times between airports.

The routing or circuity index (RI) equals zero when the routing factor exceeds a certain limit. The maximum routing factor for distance is typically 1,25 (Bootsma, 1997). However, since we take in-flight time as the input for the routing factor instead of Great Circle Distance, we should allow some time for take-off and landing. Therefore, we have added 0.15 points to the maximum routing factor. This results in a maximum routing factor of 1.4.
The routing of circuity index (RI) equals 1 when total in-flight time for an indirect connection equals 0. This is an impossible situation because of time needed for take-off and landing but it takes into account the negative impact of a transfer on the attractivity of a certain connection.

We have taken the weighted average of TI and RI. We have made the assumption that passengers perceive transfer time 2.4 times as long as in-flight time. This factor is based on preliminary research of Lijesen (2002). Future research should further distinguish between perception of in-flight versus transfer time for leisure and business passengers.

The WI-index can be aggregated in different ways. We have used:

$$WNX = \Sigma (WI)$$

Where
WNX= Total number or weighted indirect connections

**4. DATA**
The data set used consists of OAG/ABC data for the years 1990 – 1999. The OAG/ABC data set contains variables based on published information on scheduled flights. Variables include airline, flight number, departure time, arrival time, departure airport, destination airport, flight frequency, airplane type and seat capacity for each flight and the number of stops during the flight. The data are based on a representative week of July of each year. For our analysis, we took all flights departing and arriving on Wednesday.
The OAG/ABC[4] data suffer from a number of limitations. First, OAG data only provides insight into scheduled flights and not into realized demand or supply. Load factors, weather conditions, technical problems and congestion can lead to differences between the two. Given that we are interested in the structure of the aviation network, we do not consider this to be much of a problem. Second, the OAG data only registers scheduled services. We have deleted full freight flights from the data set and consider passenger flights (including the so-called 'combi' flights) only. Finally, the original data set only lists direct flights.

[4] For a detailed description see Burghouwt & Hakfoort (2001)

Minimum connection times were derived from the Official Airline Guide of 1999 for the analysis presented in section 5.

## 5. AIRLINE FLIGHT SCHEDULE EFFECTS: INDIRECT CONNECTIVITY

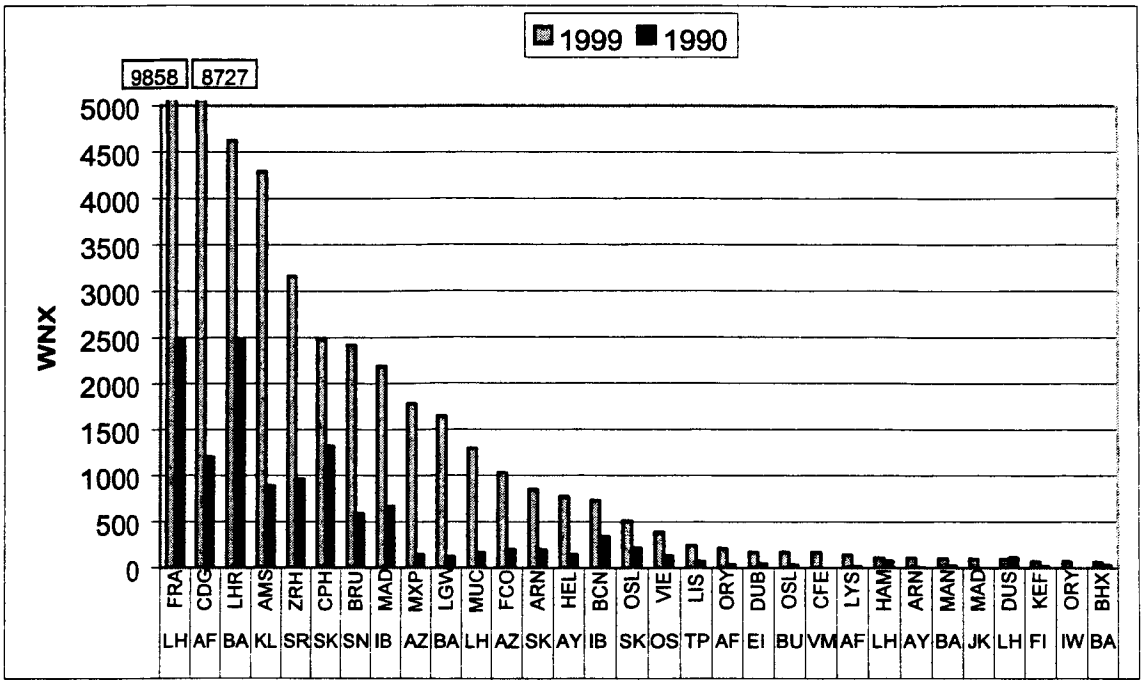
Using the methodology described in section 3, we will discuss the outcome of the flight schedule coordination in terms of indirect connectivity. To do so, we will use the WNX index of indirect connectivity. WNX is the number of indirect connections weighted by transfer time and routing factor.

### 5.1 Indirect connectivity

Figure 3 shows the WNX index for the top 31 European hubs in terms of indirect connections in 1999. In 1999, Frankfurt, Paris CDG, London Heathrow and Amsterdam dominated the market for indirect connections.

KLM at Amsterdam significantly improved its position as a hubbing carrier during the period of analysis. The carrier added an extra wave structure to the daily wave structure system, achieving a competitive frequency at Schiphol without a large investment in aircraft (see also section 6) (Caves, 1997). Air France started hub operations at Paris Charles de Gaulle in March 1996 with five waves a day (Dennis, 2001) with another $6^{th}$ wave added by 1999 (figure 4). This resulted in an increase of the WNX values by a factor 7.
In contrast, BA at London Heathrow faced a relative decline in its competitive position for transfer traffic compared to the other major hub. From a first position in 1990, BA at London Heathrow moved to a third position in 1999.
We can observe some new hubbing strategies among the national carriers. Alitalia made use of the newly constructed airports of Milan Malpensa to increase indirect connections significantly compared to the hub position of the old airport Milan Linate. Malpensa overtook Rome Fiumicino's position as the primary hub for Alitalia (Dennis, 2001).
British Airways started to build up hub operations at London Gatwick because of capacity problems at Heathrow that prevent the carrier from implementing a wave structure at that airport. BA reorganized their schedules from and to Gatwick in order to allow connections within 26 minutes in Gatwicks North Terminal (Caves, 1997). However, as we will see in section 6, the wave-system structure is still very weak compared to wave-system structures of hubs such as Paris CDG and Frankfurt.

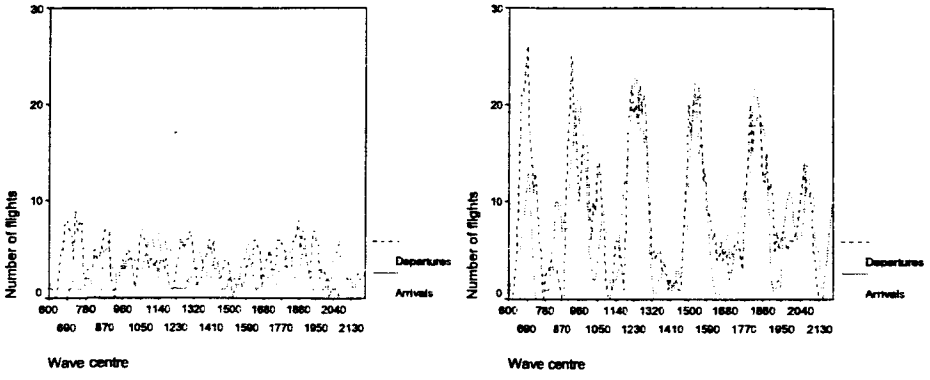
*Figure 3 Number of weighted indirect connections (WNX) in 1990 and 1999 for the primary European airline hubs*




*Source: OAG/ ABC; own calculations. Note that WNX value for Alitalia (AZ) at Milan (MXP) are values for Malpensa in 1999 and Linate in 1990. WNX values for Oslo are for Fornebu in 1990 and Gardemoen in 1999. See appendix for carrier and airport codes.*

Munich saw it indirect connectivity increase by a factor seven as a result of Lufthansa's policy to shift some of the service from Frankfurt because of capacity restrictions and the opening of the new airport in 1992. Sabena intensified its Brussels hub, mainly on the intra-European market. However, both Munich and Brussels suffer from the fact that most of the connections have a large routing factor, resulting from the fact that they are orientated towards intra-European indirect connections. Intra-European indirect connections are not as attractive as intercontinental connections because of the large transfer time compared to in-flight time. This factor has slowed down the growth of the indirect connectivity.

*Figure 4 Wave-system structure of Air France at Paris CDG in 1990 (left) and 1999 (right)*




*Source: OAG/ ABC*

At the lower level of the airport hierarchy, regional hub strategies have emerged. Dennis (2001) argues that the introduction of regional jets, such as the Embraer 145 and the Candadair Regional Jet, has facilitated the growth of these niche hubs. Regional Airlines implemented a wave structure system at Clermont-Ferrand. Air France started regional hub operations at Lyon. However, the weighted number of indirect connections generated by these carriers remains very small compared to the large hubs. They can only be successful when located far enough from the large hubs (Lyon, Clermont-Ferrand, Crossair at Basel/Mulhouse, Maersk at Billund) or in an alliance with a major carrier (Crossair at Zürich).

### 5.2 Geographical submarkets

Being an overall airline hub does not mean being an airline hub in all market segments. A clear market division can be observed between the different airline hubs. For the 15 main European airline hubs, we have analysed the competitive strength in terms of the number of weighted indirect connections in eight geographical submarkets for the year 1999:

1. From Europe to Europe (EUR-EUR)
2. From Europe to Eastern Europe (EUR-ESE)
3. From Europe to North America (EUR-NAM)
4. From Europe to Latin America (EUR-LAM)
5. From Europe to Asia and the Pacific (EUR-APA)
6. From Europe to Africa (EUR-AFR)
7. From Europe to Middle East (EUR-MEA)
8. Between non-European submarkets (directional)

Analysing the submarkets, we can divide the airline hubs roughly into four categories: the allround hubs, the specialized hinterland hubs, the European hubs and the directional or hourglass hubs (figure 5 and table 3).

*The 'allround' hubs*

Only a few 'allround' hubs can be distinguished (figure 5). Allround hubs are hinterland hubs: hubs with a high degree of indirect connectivity from hinterland Europe to all geographical submarkets. Allround hubs are also directional or hourglass hubs for an airline. They do not only offer hinterland connections but also 'hourglass' connections between different continents.

The European allround hubs are Frankfurt (LH), London Heathrow (BA), Amsterdam (KL), Paris CDG (AF) en Zürich (SR). Amsterdam and London Heathrow perform poor in the Eastern-European market. London Heathrow has also a bad position in the Southamerican market and is somewhat biased to the North American market. About 30 % of its indirect services from European airports are directed towards this market. London Gatwick could be considered as an allround hub. However, its Asia-Pacific market is very poorly developed.

*Specialized hinterland hubs*

A number of airline hubs has a bias towards one or a number of intercontinental submarkets, such as Brussels, Madrid, Milan Malpensa, Munich, Paris Orly and Dublin. Moreover, they do not provide significant service to all of the submarkets nor do they have large numbers of hourglass connections. We call these hubs specialized hinterland hubs.

Most of the geographical biases seem to be related to historical relations with the area considered. Others are based on geographical proximity. Munich and Vienna are clearly biased towards the Eastern European market for their transfer traffic, which is related to the geographical location of both hubs (Allett, 2002). Madrid devotes a large share of indirect connectivity to Latin American destinations whereas Brussels and Paris Orly have a comparatively large share of indirect connectivity direct towards Africa. Aer Lingus' hub Dublin has a bad position in a geographical sense (RI=0,1) for intra-EU traffic but strongly orientated towards North America.

*Table 3 Categorization of airline hubs in 1999 by weighted indirect connectivity and market orientation*

| | | Market orientation | | | |
|---|---|---|---|---|---|
| | | Allround | Biased hinterland | European | Directional |
| Number of weighted indirect connections | High (>2500) | Amsterdam (KL)<br>Zürich (SR)<br>Frankfurt (LH)<br>Paris CDG (AF)<br>London Heathrow (BA) | | | |
| | Medium (500-2500) | | Brussels (SN)<br>London Gatwick (BA)<br>Munich (LH)<br>Madrid (IB)<br>Milan MXP (AZ) | Copenhagen (SK)<br>Rome FCO (AZ)<br>Stockholm Arlanda (SK)<br>Helsinki (AY)<br>Barcelona (IB)<br>Oslo (SK) | Vienna (OS) |
| | Low (<500) | | Paris Orly (AF)<br>Reykjavik (FI)<br>Dublin (EI) | Clermont-Ferrand (VM)<br>Lisbon (TP)<br>Olso (BU)<br>Lyon (AF)<br>Hamburg (LH)<br>Stockholm Arlanda (AY)<br>Manchester (BA)<br>Madrid (Spanair)<br>Düsseldorf (LH)<br>Paris Orly (IW)<br>London Stansted (FR)<br>Vienna (VO)<br>Cologne (LH)<br>Stavanger (BU)<br>Bergen (BU)<br>Birmingham (BA)<br>Milaan Linate (AZ) | |

*Source: OAG/ ABC; own calculations. See appendix for carrier codes*

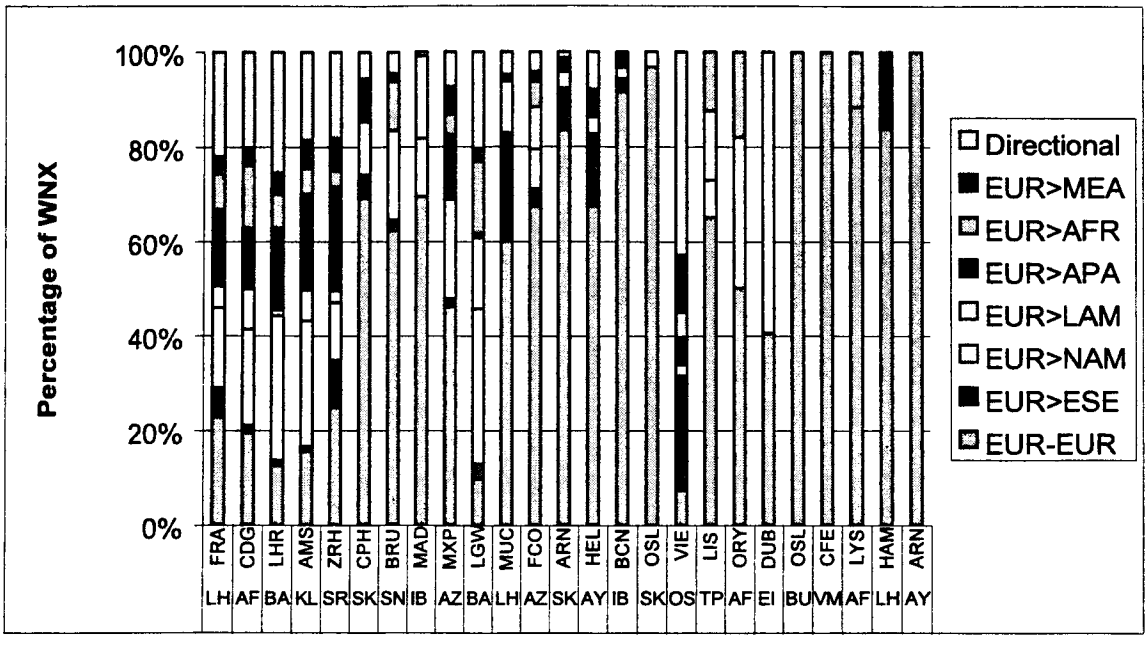
*European hubs*

Airline hubs such as Copenhagen, Rome Fiumicino, Stockholm Arlanda, Helsinki, Barcelona, Oslo, Lisbon, Clermont-Ferrand, Lyon and Hamburg offer a number of indirect connections but these are mainly intra-European (over 70% European). This kind of transfer traffic seems to be the most vulnerable one. On the one hand, more and more indirect intra-European services will be replaced by direct, point-to-point services because of the introduction of regional jets and the growth of low-cost carriers as well as the construction of the high-speed rail network. On the other hand, European hubs suffer from large routing factors because of the short in-flight time compared to the transfer time at the hub airport.

*Directional or hourglass hubs*

These are the airports offering indirect connections between different continents. Austrians hub Vienna is the only hourglass hub in Europe. It mainly offers connections between other continents and Eastern Europe. However, the absolute number of these connections is small compared to the directional connections of the allround hubs.

*Figure 5 Share of different geographical submarkets in total number of weighted indirect connections (WNX) for the primary European hubs. Note that only submarkets with WNX>10 have been included*




*Source: OAG/ABC; own calculations. See appendix for carrier and airport codes*

## 6. WAVE-SYSTEM STRUCTURES

In section 5 we have analysed the weighted number of indirect connections of airline hubs. We have seen that only a few airline hubs are highly competitive in the indirect market. Small airline hubs play an insignificant role outside the direct O-D markets. Therefore, for the analysis of the airline flight schedule itself, we will only consider airline hubs with a WNX value of 10 and higher in 1990 as competitors in the indirect market. This resulted in a sample of 62 airports. Subsequently, we have analysed the sample on the presence of a wave-system structure using the methodology of section 3.1.

Have European airline adopted flight schedules characterised by a wave-system structure, one of the characteristics of hub-and-spoke networks?

*6.1 The presence of wave-system structures in airline flight schedules*

Hub-and-spoke networks need both spatial and temporal concentration of flights. Burghouwt et al. (2003) have concluded that most airline networks, especially national airline networks, were already heavily concentrated in space in the regime of bilateral regulation. Only a few regional airlines demonstrate spatial concentration strategies. A

development towards temporal concentration into wave-system structures can be observed however.

Based on the sample of 62 airline stations, we can conclude that European airlines have increasingly adopted wave-system structures or intensified the existing structures (table 4). The number of airline hubs (those airline stations with a wave-system structure) doubled during the period of analysis. A number of airlines intensified the wave-system structure by adding more waves or increasing the quality of the wave-system structure (table 5). Only one airport was 'de-hubbed': Lufthansa's Cologne. After the German Government moved its headquarters to Berlin, the importance of Cologne/ Bonn airport decreased ad did the role of the airport in the network of Lufthansa.

*Table 4 Presence and quality of wave-system structures for a sample of 62 airline stations (airports) with more than 10 daily indirect connections in 1999, 1990 and 1999*

| Presence and quality of wave-system structure | Number of airline stations | |
|---|---|---|
| | 1990 | 1999 |
| absent | 52 | 40 |
| very poor | 5 | 6 |
| poor | 1 | 2 |
| limited | 3 | 3 |
| good | 1 | 10 |
| very good | 0 | 1 |
| TOTAL | 62 | 62 |

*Source: OAG/ ABC; own calculations*

*Table 5 Presence of wave-system structures[5] (wss) and number of waves, 1990 and 1999 for primary European hubs (WNX>10)*

| | | Quality of wave-system structure | | Number of waves | |
|---|---|---|---|---|---|
| | | 1990 | 1999 | 1990 | 1999 |
| Air France | Paris CDG | absent | good | | 6 |
| Air France | Lyon | absent | good | | 3 |
| Air France | Marseille | absent | absent | | |
| Air France | Paris Orly | absent | very poor | | 3>4 |
| Finnair | Stockholm Arlanda | absent | absent | | |
| Finnair | Helsinki | absent | very poor | | 2>3 |
| Finnair | Turku | absent | absent | | |
| Alitalia | Rome Fiumicino | very poor | poor | 2 | 5 |
| Alitalia | Milan Linate | absent | absent | | |
| Alitalia | Milan Malpensa | absent | limited | | 4 |
| BA | Birmingham | absent | absent | | |
| BA | Johannesburg | absent | absent | | |

[5] Criteria for the assessment of the quality of the wss are available from the authors upon request

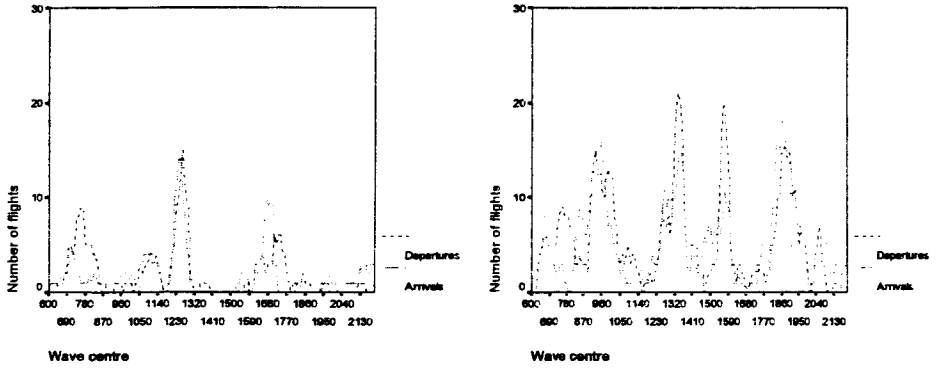
| | | | | | |
|---|---|---|---|---|---|
| BA | London Gatwick | absent | very poor | | |
| BA | London Heathrow | absent | absent | | |
| BA | Manchester | absent | absent | | |
| British Midland | East-Midlands | absent | absent | | |
| British Midland | London Heathrow | absent | poor | | 2 |
| Braathens | Bergen | absent | absent | | |
| Braathens | Oslo | absent | absent | | |
| Braathens | Stavanger | absent | absent | | |
| Braathens | Trondheim | absent | absent | | |
| Maersk | Billund | absent | absent | | |
| Maersk | Copenhagen | absent | absent | | |
| Aer Lingus | Dublin | absent | absent | | |
| Aer Lingus | Shannon | absent | absent | | |
| Icelandair | Reykjavik-Kevlavik | absent | absent | | |
| Ryanair | London Stansted | absent | absent | | |
| Air Littoral | Nice | absent | very poor | | 4 |
| Iberia | Barcelona | very poor | good | 2 | 2 |
| Iberia | Madrid | very poor | limited | 3 | 3>4 |
| Air Liberté | Paris Orly | absent | very poor | | 2 |
| AOM | Paris Orly | absent | absent | | |
| Spanair | Madrid | absent | absent | | |
| KLM | Amsterdam | limited | good | 3 | 4>5 |
| Lufthansa | Cologne | very poor | absent | 2 | |
| Lufthansa | Düsseldorf | absent | absent | | |
| Lufthansa | Frankfurt | good | good | 4 | 4 |
| Lufthansa | Hamburg | absent | absent | | |
| Lufthansa | Munich | absent | good | | 3 |
| Lufthansa | Stuttgart | absent | absent | | |
| Lufthansa | Berlin Tegel | absent | absent | | |
| LTU | Düsseldorf | absent | absent | | |
| Crossair | Basle | absent | good | | 2 |
| Crossair | Zurich | absent | absent | | |
| Lauda Air | Vienna | absent | absent | | |
| Binter Canarias | Tenerife Norte | absent | absent | | |
| Austrian | Vienna | poor | good | 2 | 4 |
| SAS | Stockholm Arlanda | absent | absent | | |
| SAS | Copenhagen | limited | limited | | 5>6 |
| SAS | Oslo | absent | absent | | |
| SAS | Stavanger | absent | absent | | |
| SAS | Tromso | absent | absent | | |
| Sabena | Brussels | limited | good | 4 | 4 |
| Swissair | Geneva | absent | absent | | |
| Swissair | Zurich | very poor | good | 3 | 7 |
| TAP Air Portugal | Lisbon | absent | very poor | | 2 |
| TAP Air Portugal | Oporto | absent | absent | | |
| Easyjet | London Luton | absent | absent | | |
| Air Europa | Madrid | absent | absent | | |

| | | | | | |
|---|---|---|---|---|---|
| Régional Airlines | Clermont-Ferrand | absent | very good | | 4 |
| Tyrolean | Vienna | absent | very poor | | 2 |
| Wideroe's | Bodo | absent | absent | | |

*Source: OAG/ ABC; own calculations.*

Air France has adopted a six-wave system at Paris CDG, reconfiguring the airport in a real traffic pump (figure 4). Alitalia has done the same at Milan Malpensa with a four-wave system. Lufthansa, as stated before, moved some of its hub operations from Frankfurt to Munich. The three waves at Munich fit exactly in the wave-system structure at Frankfurt in order to increase synergies between the two hubs. Regional Airlines, Air France, Iberia set up wave-system structures at Clermont-Ferrand, Lyon and Barcelona respectively. Crossair implemented a wave-system structure at Basel.
Some airlines intensified their hub operations during the period of analysis. KLM added two extra waves to its three-wave system (figure 6). Swissair consolidated all its intercontinental operations around Zürich (Burghouwt et al., 2002) and added four waves to its hub operations at this airport. Austrian made its operations at Vienna more efficient and added an extra wave to the wave-system structure.

*Figure 6 Flight schedule structure of KLM at Amsterdam, 1990 (left) and 1999 (right)*

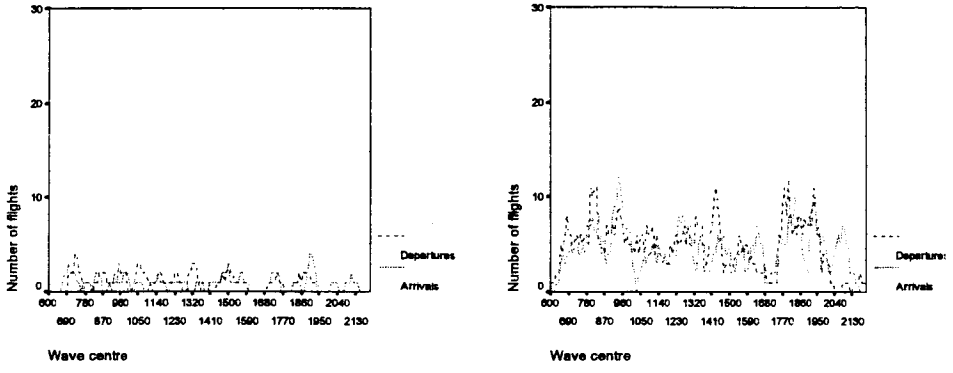



*Source: OAG/ ABC*

Four major exceptions to the temporal concentration trend exist. The majority of the airports (40 airline stations) did not have a wave-system structure in 1999.
Firstly, the major British hubs lack flight schedule coordination. British Airways was not able to implement a wave-system at Heathrow, Gatwick (figure 7), Birmingham or Manchester. Capacity shortages at these airports make it extremely difficult for the airline

to implement a schedule structure. However, the high frequencies still generate quite a large number of connections and high transfer efficiency in the case of Gatwick.

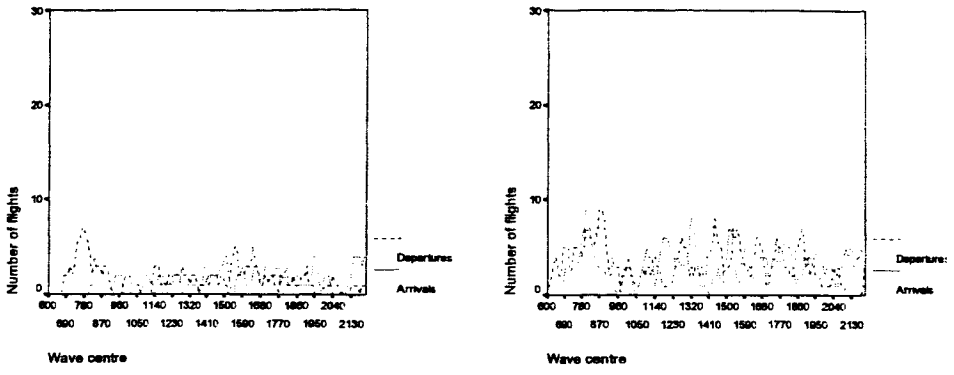
*Figure 7 Flight schedule structure of British Airways at London Gatwick, 1990 (left) and 1999 (right)*




*Source: OAG/ ABC*

Secondly, the southern European airports show no or limited wave-structures, except from Milan Malpensa and Barcelona. Their geographical position makes it difficult to compete with the traffic flows into northern Europe (Bootsma, 1997). Instead, the home carriers of these airlines seem to focus on O-D traffic and some indirect connections in the domestic and Latin-American market.
Thirdly, a number of smaller airports such as Oslo (SAS/ Braathens), Stockholm Arlanda (SAS) (figure 8), Helsinki (Finnair), London Stansted (Ryanair) and Dublin (Aer Lingus) are not hub airports in a strict sense. The network of the home carriers is to some extent centred around these airports, but a clear schedule structure is lacking. The carriers do no have specific schedules to facilitate transfers although a number of connections is generated 'by accident'. They focus on O-D traffic and/or traffic feed to the major hubs.

*Figure 8 Flight schedule structure of SAS at Stockholm Arlanda, 1990 (left) and 1999 (right)*




*Source: OAG/ ABC*

*6.2 The impact of wave-system structures on indirect connectivity*

We have seen that a number of European airlines have adopted wave-system structures in their flight schedules. Another group of carriers did not implement or did not fully implement such a wave-system structure in the flight schedule. If airlines implement a wave-structure, do these wave-system structures indeed improve significantly the total weighted indirect connectivity of a hub airport?

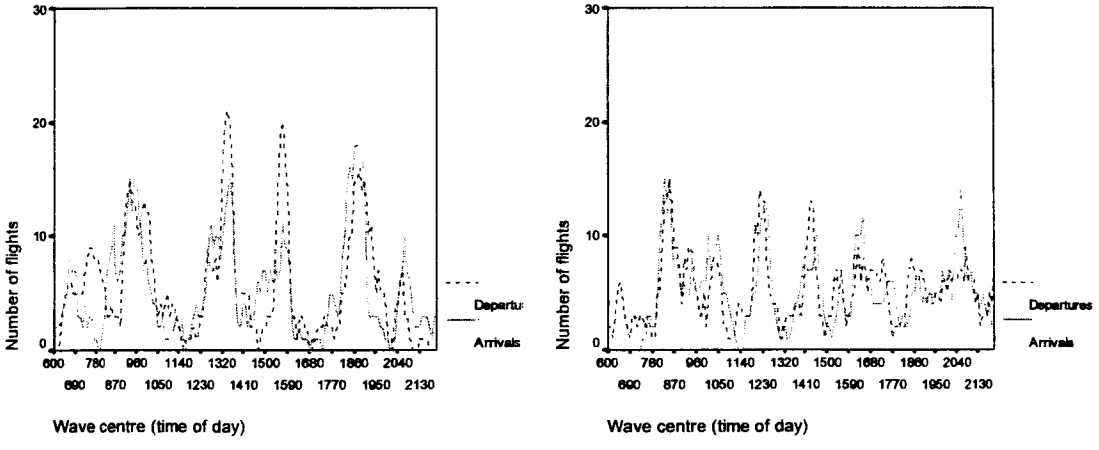
Wave-system structures indeed seem to have a positive impact on the total indirect connectivity of a hub airport. Wave-system structures have the objective to maximize the number of connecting opportunities within a limited time frame given the number of direct flights. Hence, the ratio between a given number of direct connections on the one hand and the number of indirect connections at the airline hub on the other hand should theoretically be larger for airports with a wave-system structure than for airports without a wave-system structure.

In figure 12, we have ranked the top 50 airline stations according to the number of daily direct flights in 1999. As can be expected, the ratio between the weighted number of indirect connections (x-axis) increases when the number of direct flights increases due to the quadratic nature of hub-spoke traffic. Every new direct connection results in a multiplicity of new indirect connections. Therefore, airlines offering more direct flights from an airport will show a larger ratio between indirect and direct connectivity. However, the increase in the ratio is far from constant. Increases in this ratio seem to be heavily influenced by the presence and quality of the wave-system structure. Airline hubs

with a full wave-system structure have generally a larger ratio between indirect and direct flights than carrier hubs with a poorly developed wave-system structure or without a wave-system structure.

KLM's hub at Amsterdam Schiphol for example, is comparable to Alitalia at Rome FCO in terms of the number of direct flights (figure 10). However, KLM manages to offer a lot more indirect connections per direct flight than Alitalia. KLM operates a well-developed wave-system structure at Amsterdam whereas the wave-system structure of Alitalia at Rome is somewhat less efficient because of the smaller waves and may-off wave connections (figure 9). Moreover, minimum connection times at Amsterdam are smaller than at Rome resulting in more possible connections for every arriving flight.
The result of a poorly developed wave structure system is the slow increase during the day of the total number of weighted indirect connections as in the case of Alitalia at Rome Fiumicino (figure 10). Well-developed waves offer a carrier large stepwise increases of the number of weighted indirect connections as in the case of KLM at Amsterdam Schiphol.

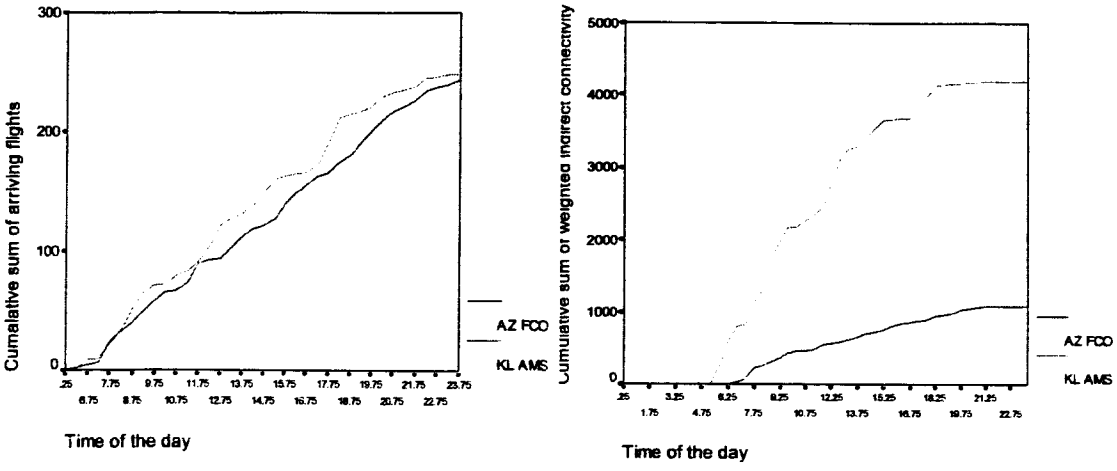
*Figure 9 Wave-system structure of KLM at Amsterdam (left) and Alitalia at Rome Fiumicino (right) in 1999*




*Source: OAG/ ABC*

*Figure 10 Cumulative number of daily direct flights for Alitalia at Rome Fiumicino and KLM at Amsterdam in 1999 per time unit (left) and the cumulative number of weighted*

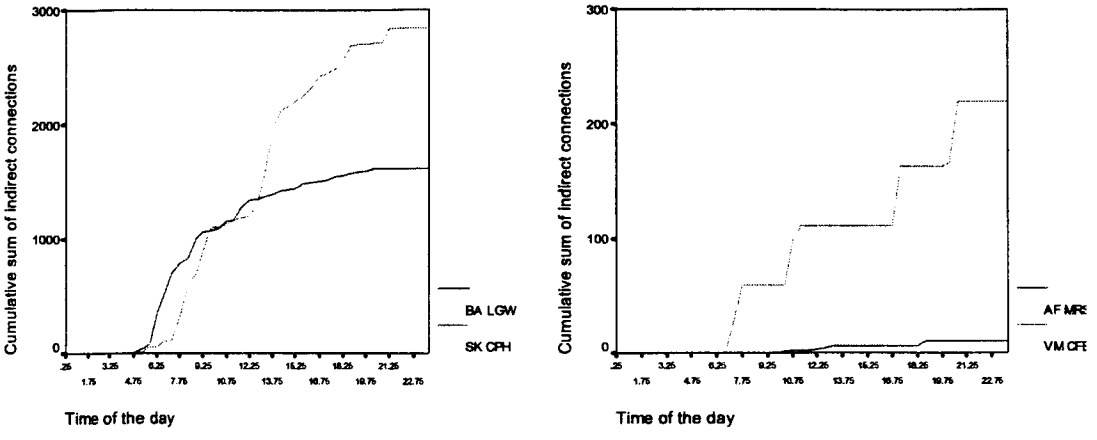
*indirect connections for Alitalia at Rome Fiumicino and KLM at Amsterdam in 1999 per time unit (right)*




*Source: OAG/ ABC*

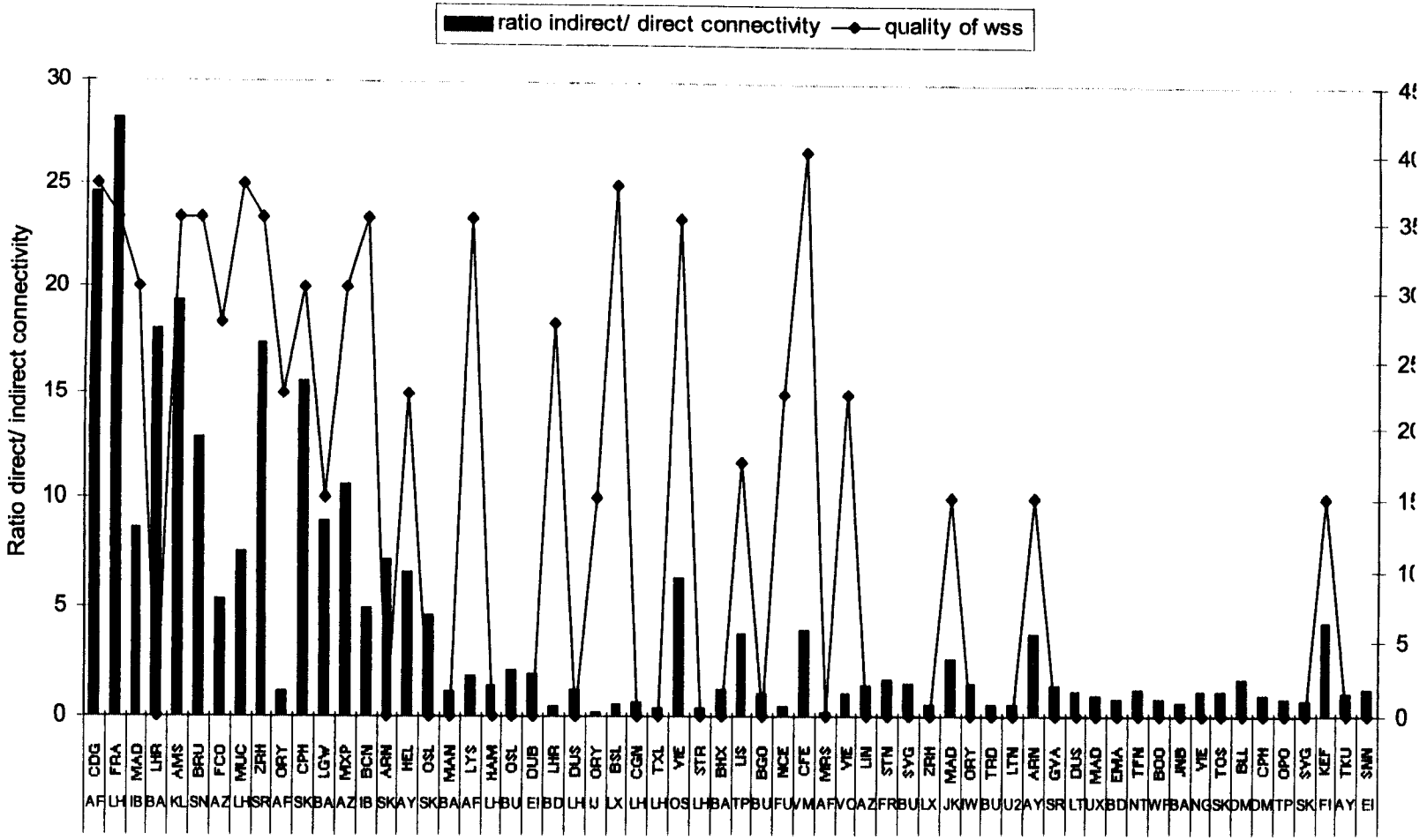
Another example is the situation of SAS at Copenhagen and BA at London Gatwick. SAS operates a full wave-system structure at Copenhagen whereas such a system is lacking at Gatwick. Both airports are comparable in terms of the number of direct daily flights. However, the number of weighted indirect connections is much larger for Copenhagen than for Gatwick as a result of the wave-system structure (figure 11, 12). The same holds true for the hub of Regional Airlines at Clermont Ferrand (with a wave-system structure) compared to Air France at Marseille without such a wave-system structure (figure 11, 12).

*Figure 11 Cumulative number of weighted indirect connections for British Airways at London Gatwick and SAS at Copenhagen (left) and the cumulative number of weighted indirect connections for Régional Airlines at Clermont Ferrand and Air France at Marseille (right)*




*Source: OAG/ ABC*

*Figure 12 Ratio between weighted indirect connectivity and the number of daily direct flights from the hub airport versus the presence and quality of the wave-system structure (40=very good; 35-37.5=good; 30-32.5=limited; 25-27.5=poor; 15-25=very poor; <15=absent)*



## 7. Conclusions and discussion

After the deregulation of the U.S. aviation market, airlines adopted hub-and-spoke networks to benefit from cost and demand side economies as well as to deter entry. The question rises if European airlines followed the same network strategy after deregulation of the EU aviation market.

The hub-and-spoke system can be considered as a network with two principal characteristics. On the one hand, spatial concentration of traffic around one or a few hub airports and on the other hand, temporal concentration of flights in a number of daily connection waves. Airports cannot be considered as real hubs as long as airlines have not implemented a clear wave-system structure. Previous research shows that the networks of major European airlines were already concentrated in space around a limited number of central airports at the beginning of deregulation. This can be explained by the system of bilateral air service agreements, that originally required airlines to only operate from their national home base (nowadays modern asa's allow to operate from any point in the national market).

What about the temporal configuration of airline networks in Europe?

A trend towards increasing temporal concentration can indeed be identified. Major European airlines implemented or intensified their wave-system structures at the major hubs during the period of analysis (1990-1999). Especially the major airlines and some niche-carriers have followed this hub-and-spoke strategy.

Most of the smaller airlines as well as the new entering low-cost airlines are focused on O-D traffic and do not play a significant role in the market for transfer traffic. An explanation for the difference between large and small carriers might be the fact that large hub-and-spoke networks have a very large demand and cost advantage in terms of the number of city pairs served compared to smaller airlines hubs. According to Oum et al. (1995), a new entrant has to compete at the entire HS network of the incumbent hub carrier and operate out of its own hub in order to compete successfully. This would be a very costly and risky undertaking. Therefore, small airlines will focus on O-D and hub-hub markets unless their hubs are sufficiently separated from the major hubs as in the case of Régional Airlines and Crossair.

The increase in wave-system structures has stimulated the number of connecting opportunities at hub airports. We have shown that airports with wave-system structures offer generally more indirect connections than airports without a wave-system structure, given a certain number of direct flights.

Between 1990 and 1999, the adoption of wave-system structures by airlines and the overall growth of frequencies have resulted in a significant increase of indirect connections, especially for the major hubs (due to the network economies of hub-and-spoke networks). Being an airline hub does not mean being an airline hub in all submarkets. We have distinguished allround, hinterland, European and directional hubs.

We have restricted our analysis to transfers within one airline. Future research should also take into account transfer opportunities between partners of the same alliance.

European airline networks were already concentrated in space around a limited number of home bases before deregulation. The regime of bilateral regulation bounded airlines to their national airports. These radial networks were not an equivalent for hub-and-spoke networks since most transfer connections were created 'by accident'. With the deregulation of the EU air transport market from 1988 on, a second phase of airline network concentration started. European airlines concentrated their networks in time by adopting or intensifying wave-system structures in their flight schedules at central airports. Temporal concentration may increase the competitive position of the network in a deregulated market because of certain cost and demand advantages.
The second phase of network concentration in Europe has changed the context in which airport planners operate. Hub-and-spoke networks have stimulated the amount of transfer traffic at hub-airports. Transfer traffic is footloose since it can easily divert to other hub airports. Hub-and-spoke networks and the freedom of entry and exit in deregulated markets induce therefore the volatility of future airport traffic volumes and change the requirements for airport terminal lay-out (de Neufville, 1995). Within this constantly changing and uncertain arena, research on more flexible approaches to strategic airport planning in Europe will be needed.

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## Appendix: carrier and airport codes

| code | airline | code | airport | code | airport |
|---|---|---|---|---|---|
| AF | Air France | AMS | Amsterdam | MXP | Milan Malpensa |
| AY | Finnair | ARN | Stockholm Arlanda | NCE | Nice |
| AZ | Alitalia | BCN | Barcelona | ORY | Paris Orly |
| BA | British Airways | BGO | Bergen | OSL | Oslo |
| BD | British Midland | BHX | Birmingham | STN | London Stansted |
| BU | Braathens S.A.F.E. | BRU | Brussels | STR | Stuttgart |
| EI | Aer Lingus | BSL | Basle | SVG | Stavanger |
| FI | Icelandair | CDG | Paris Charles de Gaulle | TRD | Trondheim |
| FR | Ryanair | CFE | Clermont-Ferrand | TXL | Berlin Tegel |
| FU | Air Littoral | CGN | Cologne | VIE | Vienna |
| IB | Iberia | DUB | Dublin | ZRH | Zurich |
| IJ | Air Liberté | DUS | Dusseldorf | | |
| IW | AOM | FCO | Rome Fiumicino | | |
| JK | Spanair | FRA | Frankfurt | | |
| KL | KLM | GVA | Geneva | | |
| LH | Lufthansa | HAM | Hamburg | | |
| LT | LTU | HEL | Helsinki | | |
| LX | Crossair | LGW | London Gatwick | | |
| OS | Austrian Airlines | LHR | London Heathrow | | |
| SK | SAS | LIN | Milan Linate | | |
| SN | Sabena | LIS | Lisbon | | |
| SR | Swissair | LTN | London Luton | | |
| TP | TAP Air Portugal | LYS | Lyon | | |
| U2 | Easyjet | MAD | Madrid | | |
| UX | Air Europa | MAN | Manchester | | |
| VM | Régional Airlines | MRS | Marseille | | |
| VO | Lauda Air | MUC | Munich | | |

# Determination and applications of environmental costs at different sized airports: aircraft noise and engine emissions

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**Abstract**

With the increasing trend of charging for externalities and the aim of encouraging the sustainable development of the air transport industry, there is a need to evaluate the social costs of these undesirable side effects, mainly aircraft noise and engine emissions, for different airports. The aircraft noise and engine emissions social costs are calculated in monetary terms for five different sized airports, ranging from hub airports to small regional airports. The number of residences within different levels of airport noise contours and the aircraft noise classifications are the main determinants for accessing aircraft noise social costs. Whist, based on the damages of different engine pollutants on the human health, vegetation, materials, aquatic ecosystem and climate, the aircraft engine emissions social costs vary from engine types to aircraft categories. The results indicate that the relationship appears to be curvilinear between environmental costs and the traffic volume of an airport. The results and methodology of environmental cost calculation could input for to the proposed European wide harmonised noise charges as well as the social cost benefit analysis of airports.

**Keywords:** environmental costs, airport operation, European Commission policy

## 1. INTRODUCTION

Over the years, increasing attention has been paid to the sustainable development of the aviation sector. More and more, environmental and social concerns are posing a severe limitation to the growth of the air transport industry. Although the global economic downturn and political turmoil has caused a decline in the number of flights and passengers over the past two years, these concerns remain valid.

It is now widely recognised that the costs of these externalities must be internalised and paid for by the aviation industry and its users [EC, 1999, 2001]. Two of the most important externalities generated from commercial flights are noise nuisance and aircraft engine emissions. From these two, noise nuisance has the largest impact on the community surrounding airports, while engine emissions have both local and global impacts.

Noise causes both nuisance and health effects, for instance sleep deprivation. More and more airports in the world, often forced by governments, have applied different types of noise management measures that range from noise abatement procedures to limits on the total noise allowed. Among these measures are night flight restrictions, night quotas, and noise charges and penalties. In 1999, only 10 out of the 27 enlarged European Union countries, Norway and Switzerland have some forms of noise charges [Lu, 2000]; in 2003 all 27 countries have noise related charges [Boeing, 2003].

Aircraft engine emissions have extensive impact on human health, vegetation, materials, ecosystem and the climate. Aircraft exhaust pollutants and $CO_2$ emissions cause damage during landing and take-off (LTO), ground stages and during cruise mode of flights. The latter is known as the only direct human-made source of pollution in the upper troposphere and lower stratosphere and results in global warming. Compared to the introduction of noise management measures, there are fewer airports applying engine emissions mitigation measures. In 1999, engine emissions charges are in place only at some Swiss and Swedish airports [Morrell and Lu, 2000]. In 2003, no other airports have introduced these charges [Boeing, 2003]. These charges are targeted only at local emissions; the International Civil Aviation Organisation (ICAO) is working on measures targeting on the emissions during cruise mode [ICAO, 1996, 1998].

This paper provides a framework in which the environmental cost of airports is assessed. The environmental cost consists of noise and emissions costs. The noise social cost depends heavily on the density of the population surrounding the airport, whilst, engine

emissions vary according to the number of flights and the aircraft types used at an airport. The calculation of environmental costs can be used in various types of analyses. The methodology can serve as a common basis for the determination of unit noise charges in the noise charge calculation formula proposed by the European Commission [EC, 2001]. Furthermore, the results can be used to assess the environmental impact of airport expansion plans and traffic forecasts. The environmental costs can also be compared with the social and economic benefits of an airport in order to assess the relationship between the airport and the surrounding region, as to when growth of the airport would lead to more environmental cost than it would yield economic benefit.

This paper presents the methodology for calculating the noise and emission social costs. The empirical analysis is carried out for three British airports (London-Heathrow, London-Gatwick and London-Stansted airports) and two Dutch airports (Amsterdam Airport Schiphol and Maastricht Airport). Various applications of the environmental cost results are addressed and investigated. Conclusions are discussed in the final section.

## 2. NOISE SOCIAL COST ESTIMATION: METHODOLOGY AND MODEL

The hedonic price method, which is applied here for calculating the aircraft noise social cost, is based on the household equilibrium marginal willingness to pay. According to Lu and Morrell [2001] the hedonic price method is the most widely used method for the evaluation of noise social costs. It is used to extract the implicit prices of certain characteristics that determine property values. Examples are location, attributes of the neighbourhood and community, as well as environmental quality [Johansson, 1987; Nelson, 1980, 1981]. For this approach, however, it is necessary to assume that each individual has the same utility function, in order to obtain the unique price estimation for noise impacts [Pearce and Edwards, 1979].

By using the hedonic price method, the annual total noise social cost $C_n$ is derived from the following formula:

$$C_n = \sum_i I_{NDI} P_v (N_{ai} - N_0) H_i \qquad (1)$$

Where $I_{NDI}$ is the noise depreciation index (NDI) expressed as a percentage; $P_v$ is the annual average house rent in the vicinity of the airport and $I_{NDI} P_v$ is the annual noise social cost per residence per A-Weighted decibel (dB(A)). The noise level above the ambient level is $N_{ai} - N_0$, where $N_{ai}$ is the average noise for the i-th section of the

noise contour; $N_0$ is the background noise or the ambient noise. This is finally multiplied by $H_i$, the number of residences within the i-th zone of the noise contour.

The NDI or the percentage reduction of house price per dB(A) above background noise, is derived from various studies using regression functions. The annual house rent $P_v$ is converted from the average house value in the vicinity of the airport by the mortgage interest rate and the average house lifetime.

It should be noted that the noise level versus annoyance curve is in a form of non-linear relationship, the higher the level of noise, the increasingly greater annoyance [Finegold et al., 1994; Schultz, 1978]. Therefore, $I_{NDI}P_v$ in the formula (1) is adjusted by the noise versus annoyance function in order to reflect the real noise nuisance imposed on the residents surrounding the airport.

After calculating the aggregate noise social cost, the question leads to how to allocate this total external cost to individual flights. The principle of this process should be based on the real impact of noise nuisance on the residents, generated dynamically from each specific flight. The factors influencing the noise impact include aircraft types, engine types, time of a day, flight paths as well as landing and take-off procedures. According to the availability of the data during the research period, a simplified approach for deriving the marginal noise nuisance, caused by each specific engine/aircraft combination flight was developed [Lu, 2000; Swan, 1999].

## 3. ENGINE EMISSIONS SOCIAL COST ESTIMATION: METHODOLOGY AND MODEL

Differences in aircraft operation and engine types, emission rates and airport congestion are considered as important parameters influencing the damage level of pollutants. The air pollution at ground level resulting from the landing and take-off of flights is distinguished from the cruise level impact, the latter of which is not taken into account in the present paper.

The calculation of the engine emissions social cost is the opposite approach from calculating the noise costs. First, the social costs for individual aircraft movements with specific engine type and standard flight modes are derived, applying the unit social cost for each pollutant. Second, the annual social cost could be determined by summing across the annual aircraft movements and emissions inventory.

$F_{ij}$, the amount (kilograms) of the jth pollutant emitted during the ith flight mode, can be derived from the following formula:

$$F_{ij} = t_i f_i e_{ij} \tag{2}$$

Where $t_i$ is the time spent during the ith mode (hours); $f_i$ the fuel flow during the ith mode (kg/hr); $e_{ij}$ the emission indices of the jth pollutant during the ith mode (kg pollutant/kg fuel). Equation (3) shows the calculation of $C_{ek}$, the social cost per flight for the kth engine/aircraft combination (€/flight):

$$C_{ek} = \sum_{j=1}^{6} \sum_{i=1}^{5} \alpha_i F_{ij} U_j \tag{3}$$

Where $\alpha_i$ is the weight for each mode (depending on the damage multiplier factor; for example 10 for cruise; 1 for the other phases of flight and ground movement, which means the same pollutant causes 10 times larger damage when emitted during cruise.); $U_j$ is the unit social cost for the jth pollutant (€/kg). Five operational modes are calculated separately, which are take-off, climb-out, approach, taxi/idle and cruise. Finally the annual emissions social cost, $C_e$, is computed as follows:

$$C_e = \sum_k D_k C_{ek} \tag{4}$$

Where $D_k$ is the total number of the annual aircraft landings for the kth engine/aircraft combination.

The unit social costs, $U_j$, are determined by Lu [2000] and are based on an extensive review of the literature [Levinson, et al., 1998; Eyre, et al., 1997; Perl, et al., 1997; Mayeres, et al., 1996]. In the literature, environmental costs are estimated in monetary terms; they are based on the relationship between pollution and damages on human health, vegetation, buildings, climate change and global warming. This method traces the links between air emissions and adverse consequences, considered as the best proved method for evaluating the social cost of emissions [Small and Kazimi, 1995].

Pollutants taken into account are HC, CO, $NO_x$, $SO_2$, $CO_2$ and $N_2O$. Since, except for Nox [Archer, 1993], there is no definite conclusion [IPCC, 1999; Peper, 1994] on the damage of pollutants emitted during cruises, only Nox is taken into account.

## 4. CASE STUDIES: DATA AND ASSUMPTIONS

Three British airports (London-Heathrow, Gatwick and Stansted airports) and two Dutch airports (Amsterdam Airport Schiphol and Maastricht Airport) are taken as the case studies for the empirical analysis. Based on the aircraft noise classification used at Heathrow Airport, aircraft types are categorised into 7 categories, with a representative aircraft type being selected for each of the categories, as shown in Table 1. The various aircraft types for different categories are listed in Appendix A.

**TABLE 1 Aircraft categorisation**

| Category | Aircraft | Representive aircraft |
|---|---|---|
| 1 | Propeller aircraft | Jetstream 31 |
| 2 | Chapter 3 jets: short haul | B737-300 |
| 3 | Chapter 3 jets: wide-body twins | A310-200 |
| 4 | Chapter 3 jets: 2nd generation wide body multi-engines | B747-400 |
| 5 | Large chapter 2/3 jets: 1st generation wide-body | B747-100F/200/300 |
| 6 | 2nd generation twin jets: narrow body twins* | B737-200QN |
| 7 | 1st generation jets: narrow body multi-engines | B727 |

Note: including Chapter 2 and hushkitted versions.

Table 2 presents the aircraft movements by category in 2001 at these five airports. Heathrow has the highest number of aircraft movements, followed by Schiphol, Gatwick, Stansted and Maastricht.

**TABLE 2 Aircraft movements by category**

| Aircraft category | Heathrow | Gatwick | Stansted | Schiphol | Maastricht |
|---|---|---|---|---|---|
| 1 | 0.9% | 5.4% | 10.3% | 3.8% | 78.4% |
| 2 | 69.8% | 74.1% | 69.7% | 78.6% | 16.2% |
| 3 | 16.3% | 13.8% | 2.0% | 6.2% | 0.0% |
| 4 | 10.1% | 1.9% | 1.8% | 6.4% | 0.0% |
| 5 | 2.4% | 2.9% | 0.7% | 4.6% | 0.0% |
| 6 | 0.1% | 1.7% | 15.2% | 0.4% | 2.7% |
| 7 | 0.4% | 0.2% | 0.3% | 0.0% | 2.7% |
| Total movements | 463,568 | 252,453 | 169,578 | 456,700 | 59,248 |

Source: UK CAA, 2002a,b,c; Schiphol Group, 2001 and Maastricht Airport, 2003.

Tables 3 and 4 show the number of residences within each noise contour zone, which is calculated using the fleet mix and number of movements in 2001. Different noise measurements are used in these two countries: Leq is used in the UK; Kosten Unit (KU) in the Netherlands. Heathrow has more than 100 thousand of residences living within 57 Leq noise contour; Schiphol also have around 122 thousand of residences live within the 20 Ku noise contour in the vicinity of the airport. The 57 Leq and the 20 Ku noise contours are the lowest noise levels measured. Although Maastricht has the least aircraft movements (Table 2), there are more residences affected by noise nuisance than those at Gatwick and Stansted (Tables 3 and 4).

**TABLE 3 Residences within noise contour at Heathrow, Gatwick and Stansted airports***

| Leq level (dBA)** | Heathrow | Gatwick | Stansted |
|---|---|---|---|
| >72 | 653 | 22 | 13 |
| 69~72 | 2,304 | 22 | 13 |
| 66~69 | 6,391 | 87 | 17 |
| 63~66 | 14,522 | 217 | 130 |
| 60~63 | 23,087 | 435 | 391 |
| 57~60 | 57,565 | 1,478 | 435 |
| **Total** | **104,522** | **2,261** | **1,000** |

Source: UK CAA, 2002a,b,c.

Note:

* The average persons per household (2.3), from the UK statistics office, are applied for converting affected population into residences.

** 51 Leq is used as the background noise level for the calculation in the next section. Note the number of residences within the noise contour 57 to 51 Leq is unknown. The inclusion of these would lead to higher noise social costs.

**TABLE 4 Residences within noise contour at Schiphol and Maastricht airports**

| Kosten Unit (KU)* | Schiphol |
|---|---|
| >65 | 14 |
| 60~65 | 33 |
| 55~60 | 70 |
| 50~55 | 402 |
| 45~50 | 1,675 |
| 40~45 | 3,358 |
| 35~40 | 3,857 |
| 30~35 | 13,539 |

| Kosten Unit (KU) | Maastricht |
|---|---|
| 40~65 | 0 |
| 35~40 | 176 |
| 20~35 | 1,440 |
| 10~20 | 11,671 |

| | | | |
|---|---|---|---|
| 25~30 | 44,048 | | |
| 20~25 | 55,634 | | |
| **Total** | **122,630** | **Total** | **13,287** |

Source: Schiphol Group, 2002; Maastricht Airport, 2002.

Note: * 10 KU is used as the background noise level for the calculation in the next section. Note the number of residences within the noise contour 20 to 10 KU is unknown. The inclusion of these would lead to higher noise social costs.

The average NDI value concluded from a number of research papers is within 0.60-0.62% with Noise Exposure Forecast (NEF) as a noise descriptor[1]. KU used in the Netherlands ranges from 20 to 65 KU, which is 1.5 times the range compared to NEF's 20-50. Therefore, the NDI value is adjust to 0.40% for the calculation of noise social costs at Dutch airports. On the other hand, based on the narrower range of the Leq system, the NDI value is set at 1.00% for the UK airports. The average housing prices at the airport area are listed in Table 5. Table 6 presents the unit social costs for each of the pollutants from engine emissions.

**TABLE 5 Housing prices in 2001**

| Airport | Housing price (€/residence) |
|---|---|
| Heathrow | 260,394 |
| Gatwick | 230,130 |
| Stansted | 201,077 |
| Schiphol | 168,000 |
| Maastricht | 151,000 |

Source: UK CAA, 2002a,b,c; Schiphol Group, 2002 and Maastricht Airport, 2002.

**TABLE 6 Unit social costs of pollutants from engine emissions**

| €/kg | HC | CO | $NO_x$ | $SO_2$ | $CO_2$ | $N_2O$ |
|---|---|---|---|---|---|---|
| Social cost | 3.49 | 0.07 | 9.69 | 51.71 | 0.02 | 1.03 |

Source: Derived from the data listed in Lu [2001] and converted to the 2001 value.

[1] NEF (Noise Exposure Forecast), one of the cumulative noise event measures, reasonably varying between 20-50, was mostly used in the United States prior to the development of the $L_{dn}$ index.

## 5. CASE STUDIES: EMPIRICAL RESULTS

The social costs calculation is based on the annual airport movements, the current fleet mix and the number of the residences annoyed, which means that the cost level varies as the endogenous or exogenous parameters are changed. For example, if airlines reduce the number of flights to an airport, or change the types of engines for some aircraft types, the annual number of movements from the airport will be lower and different levels of emissions are generated. The corresponding environmental cost is different in order to accurately and dynamically reflect the real social cost of aircraft emissions. Furthermore, if the characteristics in the vicinity of the airport changed, the cost level would vary correspondingly. For instance, the more noise insulation investment (recycling the charges collected), the less annoyance the residents would incur. In this case, even with the same number of flights, the perceived noise nuisance of the airport would be reduced.

### 5.1 Noise social costs

The calculation results of equation (1) for noise social costs at the current aggregate noise level are presented in Table 7. The noise social costs for different aircraft categories at Heathrow vary from €28 per landing for Jetstream to €3,007 for B747-100F/200/300/SP, with the weighted average of €774 per landing (or €387 per movement). The average noise social cost at Schiphol, although having similar aircraft movements to Heathrow, appears to be €377 per landing, less than half of that at Heathrow. On the contrary, Maastricht, with least aircraft movements, but situated in a more densely populated area, has higher noise social costs than Gatwick and Stansted.

### 5.2 Engine emissions social costs

The social cost of engine emissions has been calculated on the basis of assumptions on engine types and emission rates. These assumptions are necessary because of limitations in data availability and because further complexity in terms of using every actual aircraft/engine combination would not result in significantly greater accuracy. Therefore, substituting the related parameters and data in equations (2), (3) and (4) [ICAO, 1995], the average social cost per landing for each aircraft type is shown in Table 8. As the impacts of engine emissions are less airport-specific, the social costs for individual aircraft types are assumed the same for all five airports.

**TABLE 7 Noise social cost by aircraft category (€/landing)**

| Category | Aircraft type | Heathrow | Schiphol | Gatwick | Stansted | Maastricht |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | Jetstream 31 | 28 | 14 | 1 | 1 | 14 |
| 2 | B737-300 | 510 | 265 | 19 | 11 | 259 |
| 3 | A310-203 | 831 | 431 | 31 | 17 | 422 |
| 4 | B747-400 | 1,975 | 1,024 | 74 | 41 | 1,003 |
| 5 | B747-100F/200/300 | 3,007 | 1,560 | 113 | 63 | 1,528 |
| 6 | B737-200QN | 2,035 | 1,056 | 76 | 43 | 1,034 |
| 7 | B727 | 2,194 | 1,138 | 82 | 46 | 1,115 |
| | Weighted average | 774 | 377 | 25 | 16 | 111 |

**TABLE 8 Engine emissions social cost by aircraft category**

| Category | Representative aircraft type | Engine emissions cost ( €/landing) |
|---|---|---|
| 1 | Jetstream 31 | 43 |
| 2 | B737-300 | 389 |
| 3 | A310-203 | 952 |
| 4 | B747-400 | 4,839 |
| 5 | B747-100F/200/300 | 3,581 |
| 6 | B737-200QN | 448 |
| 7 | B727 | 644 |

The figures in Table 8 include not only the social cost at the ground level resulting from the standard LTO procedures, including take-off, climb-out, approach and taxi-idle modes, but also the costs of the emissions from 30 minutes' cruise either prior to landing or following take-off. The engine emissions social costs rang from €43 to €4,839 depending on aircraft types.

It should be noted that $NO_x$ is the only cruise emission included, due to the higher uncertainties of other emissions. If other pollutants were incorporated, the cost would be higher. Furthermore, the same unit social costs for each pollutant is applied to both ground level and cruise. However, it has been argued that the damage in the upper atmosphere might be 10 times higher than at ground level [INFRAS and IWW, 1995]. Therefore, the values presented in Table 8 could be considered as a conservative (lower) estimation.

### 5.3 Environmental costs

The environmental costs here are defined as the aggregation of both noise and engine emissions social costs. From Tables 7 and 8, the environmental costs for five airports are presented in Table 9 and Figure 1. The annual environmental social cost is calculated to

be €645 million for Heathrow, followed by Schiphol (€471 million), Gatwick (€161 million), Stansted (€82 million) and Maastricht (€11 million).

**TABLE 9 Average and annual environmental cost comparison**

| | Heathrow | Schiphol | Gatwick | Stansted | Maastricht |
|---|---|---|---|---|---|
| Average noise cost (€/landing) | 774 | 377 | 25 | 16 | 111 |
| Annual noise cost (million €) | 179.5 | 86.0 | 3.1 | 1.3 | 3.3 |
| Average emission cost (€/landing) | 1,004 | 842 | 626 | 477 | 126 |
| Annual emission cost (million €) | 465.6 | 384.7 | 158.1 | 80.8 | 7.5 |
| Average environmental cost (€/landing) | 1,779 | 1,219 | 651 | 492 | 237 |
| Annual environmental cost (million €) | 645.1 | 470.7 | 161.2 | 82.1 | 10.8 |

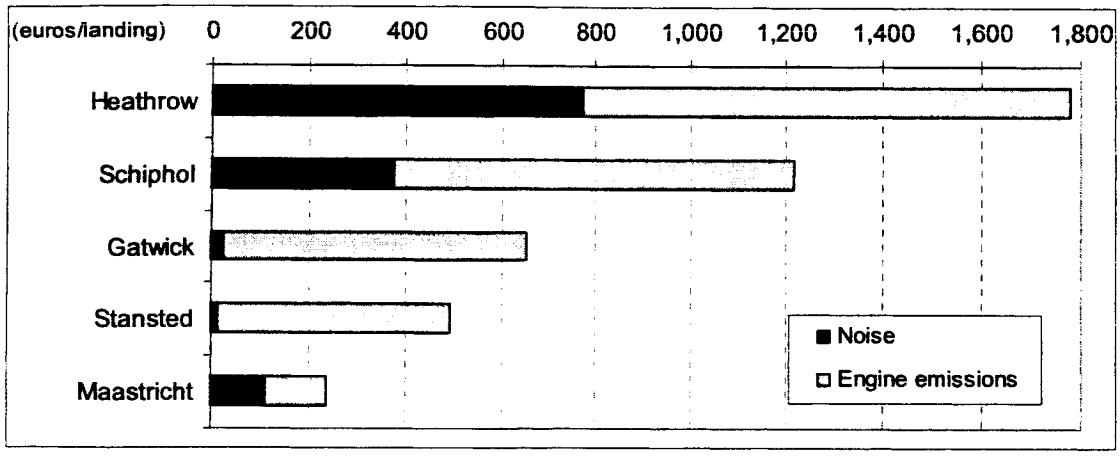



**FIGURE 1 Average environmental cost comparison**

Comparing the environmental cost with the traffic volume of an airport, the results for these five airports indicate that the relationship appears to be curvilinear between annual environmental costs and aircraft movements (Figure 2). This implies that the marginal environmental cost is increasing as aircraft movements increase. In other words, adding a certain amount of traffic to a hub airport would cause more environmental damages than that at a regional airport. Note that this comparison is only valid when the characteristics of airports are similar especially in terms of their surrounding neighbourhoods.

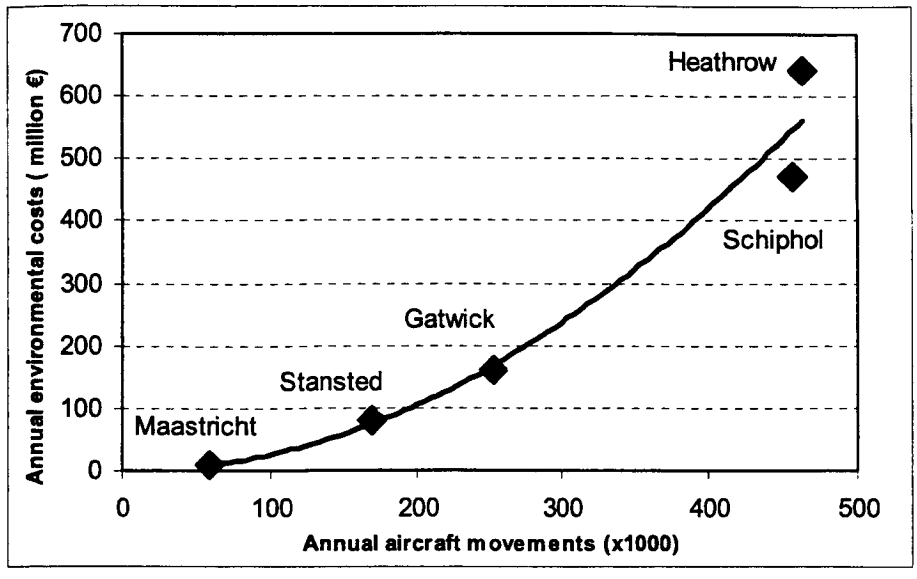



**FIGURE 1 Relationship between environmental costs and aircraft movements**

## 6. APPLICATIONS OF ENVIRONMENTAL COSTS

Next to showing the degree of the environmental impacts at various airports, several applications of this result and methodology are presented and discussed in this section. First of all, the methodology of calculating aircraft noise social costs can be used to determine the proposed European wide noise charge levels. Furthermore, the environmental costs valued in monetary terms can form the input of cost-benefit analysis of an airport or an airport system.

This section provides a brief overview of how the results can be applied. However, complete analysis of these applications is beyond the scope of this paper and requires further research. All these applications focus on the influence of an airport on the region and are to be seen from the perspective of a region.

### 6.1 European wide harmonised aircraft noise charges

One of the main objectives of the EU common transport policy is to promote the sustainable development of transport activities [EC, 1999]. The use of economic instruments is considered to be an efficient and effective way of improving the environmental performance of an airport [ICAO, 1996, 1998; OECD, 1998]. The EC's proposal for potential harmonised noise charges provides the possibility to modulate aircraft noise charges as a function of its environmental impact [ANCAT, 1998; EC, 2001]. This formula for calculating noise charges, $C$, is as follows [EC, 2001]:

$$C = C_a \cdot 10^{\frac{L_a - T_a}{10}} + C_d \cdot 10^{\frac{L_d - T_d}{10}} \quad (5)$$

where:

- $C_a$ and $C_d$ are the unit noise charges at departures and arrivals for the considered airport. They reflect the relative importance of noise emissions at arrivals and departures for the impacted population.
- $L_a$ and $L_d$ are the certificated noise levels at approach, and flyover and lateral measurement points.
- $T_a$ and $T_d$ are noise thresholds at departures and arrival corresponding to categories of relatively quiet aircraft for the considered airport.

While the certificated noise levels and the noise thresholds are known, no common and transparent method has been developed for calculating the unit noise charges, namely $C_a$ and $C_d$, at each of the European airports. The methodology of calculating noise social costs can be applied here by deriving the marginal noise impacts of different aircraft categories into a separate departure and arrival index.

Our method has taken into account various theoretical and practical aspects. Firstly, the calculation is based on both the certificated noise levels and the number of residences affected by noise, which is derived from the noise contours around airports. This implies that the methodology has fulfilled the condition that *'noise charges should be proportional to the incremental nuisance for human beings caused by individual aircraft separately at arrival and departure'* [EC, 2001]. In addition, the same approach could be practically applied to any airport, each with their own traffic and operational characteristics. Finally, for a preliminary analysis, the data needed to calculate the unit charges can be easily obtained for the majority of the European airports.

### 6.2 Cost-benefit analysis of an airport or an airport system

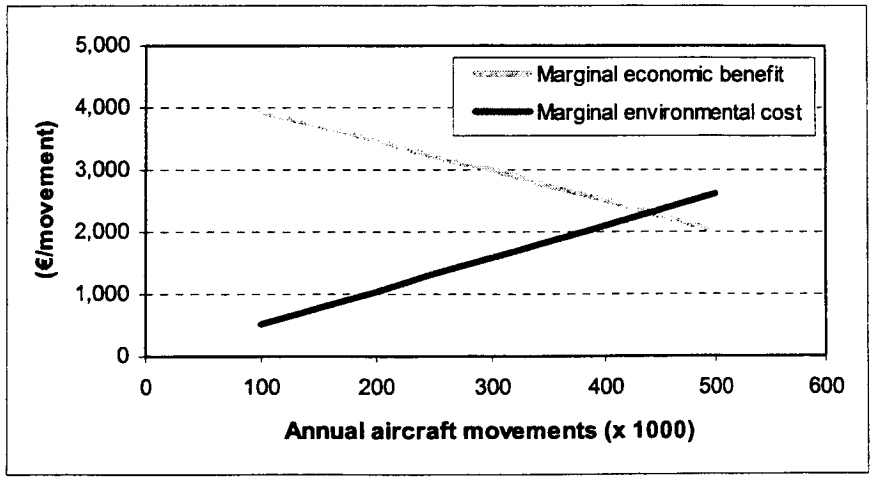
In the context of sustainability, an airport can only exist if it generates more social and economic benefits to the region or nation than its damages on human beings and the environment. Furthermore, an airport is operating most efficiently when its marginal social benefit is equal to its marginal environmental cost. Any movement beyond this threshold would result in more environmental damage than its generated benefit to the society. The same applies to an airport system. An airport system consists of a few hub

and regional airports in a geographically close area[2]. If the hub airport has reached its threshold, any additional flight would be better allocated to other airports.

So far, the method has not been fully developed for quantifying the economic benefits generated from an airport for the region. However, the existing research indicates that an airport would generate approximately some 1,000 to 1,100 jobs per one million passengers [ACI, 1998]. This figure, however, does not include the social benefit of an airport (such as accessibility of the region and public obligation).

The following analysis is done by comparing the economic benefits of an airport, resulting from employment for the region, and their environmental costs for both noise and engine emissions. However, the precise added value of an airport should be evaluated by taken into account all possible influences of an airport on the local communities and the nation. Moreover, other factors, such as external safety and congestion, would also result in environmental costs.

Based on the estimation of the total economic benefits of the case study airports and their environmental costs, Figure 2 shows the marginal economic benefit and marginal environmental cost in relation to aircraft movements by using a regression analysis. This regression analysis has been done on all 5 airports, two of which are main hubs and three are other airports. It can be argued that a main hub airport and a different type of airport have significantly different characteristics, which makes a general analysis impossible. Due to the size of the sample, it is not feasible to split it and perform a separate analysis on the hubs and on the other airports. Notably, the analysis only serves as an illustration thanks to the limited sample size; no general conclusion can be drawn from here.




[2] A good example is the London airport system, with five airports in the greater London area. Those are London-Heathrow, Gatwick, Stansted, Luton and City airports.

**FIGURE 2 Economic benefit versus environmental cost**

This figure shows that the marginal environmental cost is increasing as aircraft movements increase, while the marginal economic benefit is decreasing. The tentative results appear that the two curves intersect at approximately 450,000 movements per year. This is the level at which an airport is operating most efficiently with its marginal economic benefit equal to the marginal environmental cost. By expanding this analysis to include more airports and factors, policy makers would be able to determine the equilibrium of an airport system and to evaluate any investment or expansion of an airport.

## 7. CONCLUSIONS AND RECOMMENDATIONS

With the European Communities' policy of strengthening market incentives to improve environmental performance [EC, 1999], and the EC's proposal for a potential harmonised noise charges [ANCAT, 1998, EC, 2001], the assessment of the real social costs of those externalities is vital for those policies. The methodologies developed in this research paper for evaluating the social costs of both aircraft noise and engine emissions have been applied for different sized airports, each with their own traffic and operational characteristics.

Of all five airports, Heathrow Airport has the highest noise and engine emissions social cost which is the result of its large number of aircraft movements and high population affected by noise. With also high volume of aircraft movements and population, Schiphol, however, has lower noise and engine emissions social costs than Heathrow. Maastricht has higher noise costs than Gatwick and Stansted, but the least engine emissions costs. The environmental cost, aggregation of noise and engine emissions costs, is calculated to be €1,779 per landing for Heathrow, followed by Schiphol (€1,219), Gatwick (€651), Stansted (€492) and Maastricht (€237).

The calculation of environmental costs in monetary terms can be applied in a variety of analyses. The method can be used in determining the proposed European unit noise charges. The environmental costs can serve as an input for cost-benefit analysis of an airport and an airport system.

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## APPENDIX A: AIRCRAFT CATEGORY

| Category | Aircraft type | Category | Aircraft type |
|---|---|---|---|
| 1 | Small props | 4 | B747-400 |
| | Large props | | A340 |
| | | | MD11 |
| 2 | B737-300,400,500 | | |
| | B737-600,700,800 | 5 | B747-100 |
| | B757 | | B747-200 (Ch 2) |
| | BAe146 | | B747-200,300 (Ch 3) |
| | A319,320,321 | | DC10 |
| | Business jet (ch 3) | | Tristar |
| | CRJ Canadair Regional Jet | | |
| | ERJ Embraer EMB 135/145 | 6 | B737-200 (Ch2/3) |
| | F100 | | BAC-11, Tu134 |
| | MD80 | | DC9 |
| | MD90 | | Business Jet (Ch2) |
| 3 | B767-200 | 7 | B707 |
| | B767-300 | | B727 (Ch2/3) |
| | B777 | | DC8 |
| | A300 | | Concorde |
| | A310 | | Tu154 |
| | A330 | | VC10 |
| | | | IL62 |

# Cost Effective Measures to Reduce $CO_2$ Emissions in the Air Freight Sector

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## Abstract

This paper presents cost effective measures to reduce $CO_2$ emissions in the air freight sector. One door-to-door transport chain is studied in detail from a Scandinavian city to a city in southern Europe. The transport chain was selected by a group of representatives from the air freight sector in order to encompass general characteristics within the sector.

Three different ways of shipping air cargo are studied, i.e., by air freighter, as belly freight (in passenger aircrafts) and trucking. $CO_2$ emissions are calculated for each part of the transport chain and its relative importance towards the total amount $CO_2$ emitted during the whole transport chain is shown. It is confirmed that the most $CO_2$ emitting part of the transport chain is the actual flight and that it is in the take-off and climbing phases that most fuel are burned. It is also known that the technical development of aircraft implies a reduction in fuel consumption for each new generation of aircraft. Thus, the aircraft manufacturers have an important role in this development

Having confirmed these observations, this paper focuses on other factors that significantly affects the fuel consumption. Analysed factors are, e.g., optimisation of speed and altitude, traffic management, congestion on and around the airfields, tankering, "latest acceptance time" for goods and improving the load factor. The different factors relative contribution to the total emission levels for the transport chain has been estimated.

**Keywords:** CO2, Air freight, Transport chain, Fuel consumption, Environment, Greenhouse effect

## Introduction

Global warming is perhaps the most challenging task for our society to solve. In the Kyoto Protocol, under the United Nations Framework Convention on Climate Change (UNFCCC), has most of the industrial countries agreed to reduce their emissions of six greenhouse gases by 5 % from 1990 levels by 2008-2012. If this target shall be realised, it is likely that governments will put economic or legal pressure on the polluters. The aviation's share of the global $CO_2$ emissions are still only 2-3 percent but it contributes to about 12 % of the worlds annual transport related $CO_2$ emissions. Compared to the other means of transport is the air freight sector more exposed to fuel price fluctuations. If there will be economic means of control in order to reduce the $CO_2$ emissions from the transportation sector it will influence the competitiveness of the air freight sector in a negative way.

Fuel efficiency has traditionally been one of the most important issues for the aviation industry and impressive achievements has been made. Large resources are invested by aircraft manufacturers and research organisations to increase the fuel efficiency even more in the future. Due to the market forces is this development in full progress. There are, however, other parts in the transportation chain that can be improved. Many of these measures can be realised with better planning and improved information tools. Another barrier is the resistance against behavioural changes. The cost of these measures are often impossible to measure as the price for the transportation companies will be in terms of, e.g., lowered customer service levels. However, compared to the resources invested in technological improvements of the aircrafts fuel efficiency these behavioural and logistical measures are estimated to be low

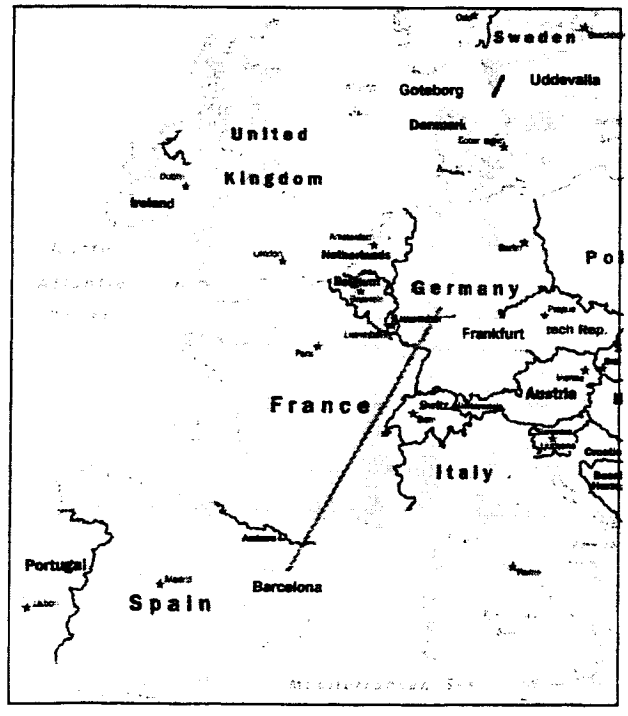
This paper aims at identifying cost effective measures to reduce $CO_2$ emissions in the air freight sector. One door-to-door transport chain is studied in detail from a Scandinavian city to a city in southern Europe. With this method can the environmental "hot-spots" in the transport chain be identified.

In spite of the fact that other factors, e.g., NOx, vapour and particulates are more aggressive greenhouse gases than $CO_2$ is $CO_2$ used as measurement for the global warming potential in this study. This is done as the primary scope of this paper is not to calculate the exact GWP for the transport chain, but to identify possible reduction possibilities. In most cases are the emissions of $CO_2$ in the transportation chain proportional to the emissions of NOx and the other greenhouse gases. In the cases where there might be a counter effect, e.g., decreased fuel consumption implies higher levels of NOx it will be discussed.

Emission calculations are made in the PIANO-Harp model in cooperation with the Department of Aviation Environmental Research, FOI – The Swedish Defence Research Agency. Information about the logistic and terminal related issues was obtained by interviews of airport and air transport company personnel.

## Description of the transport chain

One door-to-door transport chain is studied in detail from the city of Uddevalla in Sweden to Barcelona in Spain. The transport chain was selected by a group of representatives from the air freight sector in order to encompass general characteristics within the sector. The same group defined the cargo characteristics for this study to 1000 kg and 9.6 m3. The transport chain represent transportation by truck, by freighter and by belly-hold in passenger aircrafts.




The first segment of the transport chain is a truck transport in Sweden from Uddevalla to Göteborg. The truck has a maximum load weight of 26 ton and consumes 35 litres of diesel oil / 100 km (2.86 km / l). The load factor is assumed to be 70 %

The second segment is an air freight transport from Göteborg to Frankfurt, Germany in a MD-11, freighter version.

The third segment of the transport chain is from Frankfurt to Barcelona, Spain. There are no flights with freighters on this route; there are only passengers' flights that take the cargo by belly-hold. One of the most common aircraft operating this route is the Airbus 310.

**Table 1:** Summary of CO2 emissions from the studies transport chain

| Route | Transport mode | Vehicle/aircraft | Load factor | Distance (km) | Dur. time (min) | CO2/ton (kg) | CO2/tkm (gram) | CO2 total trip (kg) |
|---|---|---|---|---|---|---|---|---|
| Uddevalla-Göteborg | Truck | 26 ton | 80 % | 81 | 60 | 3 | 0.04 | 69 |
| | | | 60 % | 81 | 60 | 4 | 0.05 | 64 |
| Göteborg - Frankfurt | Air freighter | MD 11 | 80% | 981 | 83 | 431 | 0.44 | 32 100 |
| | | | 60% | 981 | 83 | 531 | 0.54 | 29 600 |
| Frankfurt Barcelona | Passenger aircraft | A310 | 80% | 1 193 | 99 | 706 | 0.59 | 19 300 |
| | | | 60% | 1 193 | 99 | 908 | 0.76 | 18 600 |
| Uddevalla - Barcelona | Truck | Max. load 26 ton | 80% | 2 492 | 2 340 | 102 | 0.04 | 2 100 |
| | | | 60% | 2 492 | 2 340 | 127 | 0.05 | 2 000 |

The calculations show that the fuel consumption increases if more cargo is loaded on the aircraft. However the environmental efficiency increases in terms of lowered $CO_2$ emissions per transported ton cargo if the load rate increases and more cargo is transported in the same aircraft.

It is also clear that a freighter is more efficient than belly cargo. This is however dependent on which allocation method that is used for the calculations. It can be argued that cargo transported in a passenger aircraft should only be allocated the emissions from burning the extra amount of fuel consumed due to the extra weight of the cargo. This allocation model is called the marginal method. To highlight the methodological dilemma on how to allocate the total emissions from an aircraft transporting both passengers and cargo are the calculations above complemented with calculations on what the outcome would be when three different allocation methods are used; by weight, by volume and by the marginal method.

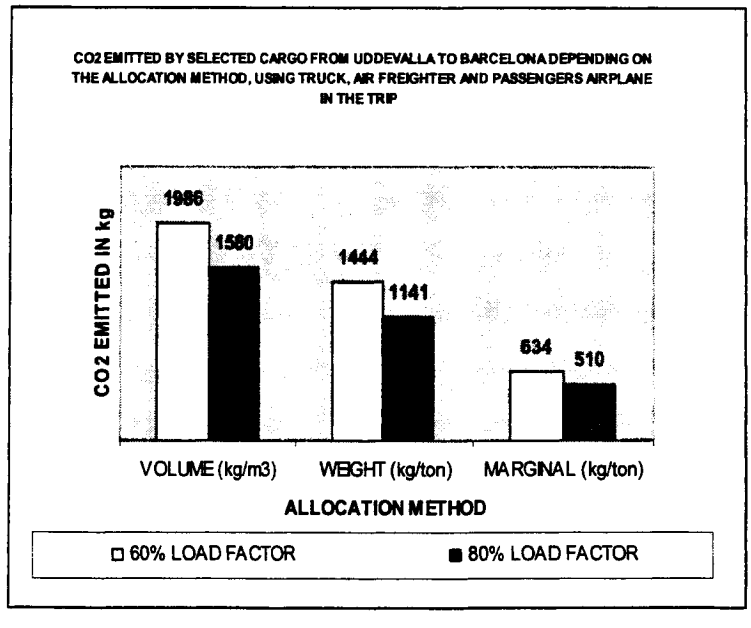



**Figure 1:** $CO_2$ from the studied transport chain, with the three allocation methods and 2 different load factors.

The difference in results are significant and it stresses the importance of transparency when showing results from an emission analysis of a transport chain. It must be clearly defined what allocation method that is used and for what purpose the study is performed.

If the emissions of $CO_2$ from air freight is compared to trucking it is clear that the truck shows the lowest figures. However, if a comparison is made in only the section Frankfurt – Barcelona for the selected cargo with the marginal allocation method, some interesting figures come out to light. It can be noted that in this segment with an 80% load factor with the marginal method there are 75 kg of $CO_2$ produced per extra transported ton of cargo on an A310 passengers' aircraft on this route. On the other hand for the same segment using a truck with 80% load factor there are 55 kg of $CO_2$ emitted. There is a difference of only 20 kg of $CO_2$. With 60 % load factor on the truck is the corresponding figure 69 kg. What method to use in different analyses is a classical issue in LCA (Life Cycle Assessment) methodology and is not discussed in this paper.

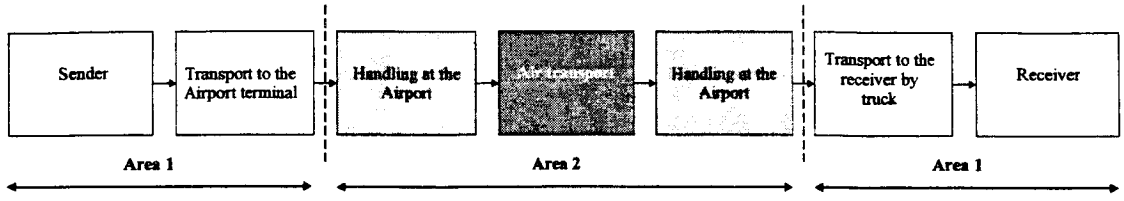
Some of the points that can be highlighted from the calculations are:

- In the phases taxi out, take off, climb out and climb 2 are about 50% of the total $CO_2$ produced for the shorter route (981 km) and about 35 % for the longer (1193 km).
- The phase of cruise produces abut 40% respective 55 % of the $CO_2$ .
- The rest of the trip which is descent 2, approach, landing and taxi in, produces about 10% of the $CO_2$.
- The 8 minutes of taxi for the MD-11 produces about 800 kg of $CO_2$. Depending on air traffic, congestions on the airports, bad weather, and any kind of delays, the taxi times generally raise. According to some average taxi times (LFV, 2001) there is an average of 26 minutes for the phases of taxi out and taxi in, which implies about 2 500 kg of $CO_2$.

## Measures to reduce $CO_2$ emissions

There are two main areas of processes in this logistic chain, there are activities outside and within the airports. The first one, includes the delivery of goods from the sender to the trucking company if there is one, the transportation of the goods, and after this the delivery to the airport terminal. The same would be on the other end of the transport chain, the pick up of goods from the airport terminal, is done directly by the receiver or by a trucking company, which later will deliver these goods to the receiver.

The second area is the one in which all the activities are held inside the airport. Flights between origin and destiny airports, including loading and unloading of goods, handling and manoeuvring of the cargo, all the technical inspections and activities related to the maintenance of the aircrafts, flight operations, all the operations included in the turnaround, etc.




This paper is structured on what can be done in the different segments.

*Area 1*

Beside the obvious measures of ensuring a high load factor on the distribution vehicles can the transport company and their customers affect the emissions of $CO_2$ by supplying the air freight transporters with accurate information and time to plan the loading of the aircraft. This will reduce the risk of unbalanced and delayed freighters.

**Latest acceptance time**

The Latest Acceptance Time is the deadline that air transporters have to receive cargo from the customer. In modern logistics, where the forwarders offer their customers a high service level, there has been a trend towards short lead times and late acceptance time. It has become an important competition factor. Together with an increased security level on air traffic after September 11$^{th}$ this has put more stress on the terminal personnel. Nowadays some air transportation companies have 1 hour of Latest Acceptance Time for cargo but the ideal time needed in order to do an efficient balance and distribution is of 2 to 4 hours before departure. The shorter the Latest Acceptance Time, the less time to organize and distribute the cargo in an optimal way in the aircraft. The only way to correct this unbalance in the air is to compensate it by increased power on the engines. For the MD-11 studied in this paper there can be savings of up to 4 - 5 % of the total fuel consumption. These figures varies from aircraft to aircraft but the principle is the same.

Other reasons for unbalances are, e.g., the shape of the cargo or the container, special quality demands on the cargo, inaccurate information from the customer about the volume or weight of the cargo.

**Delays**

The delays of air transportation causes extra emissions due to fuel burned unnecessarily. The delays can occur due to e.g., weather conditions, mechanical problems, late delivery of cargo. To give an idea of the impact of these delays in the amount of emissions produced, it is estimated that German airports in 1999 burned 50,770 tons of fuel due to delays which corresponds to about two percent of the fuel burn of the entire Lufthansa Group fleet..

To get passengers and cargo to their destinations as punctually as possible and to avoid further delays, pilots often fly faster than the optimised cruise speed (see section Aircraft Cruise speed), which result in significantly higher fuel consumption. Data on exact quantities has not been obtained.

*Area 2*

**Handling at the airport**

Airport operations in Sweden adds an extra 1.2 kg $CO_2$ per passenger (LFV, 2001). This represents about 1-3 % of the total emitted $CO_2$ depending on the flight routs. No data was available for the air freight sector separately but considering the facilities needed to supply service for passengers compared to handling the cargo it can be assumed that the additional $CO_2$ emissions for cargo handling at the airport is less than 1 %.

Auxiliary power units (APUs) are engine-driven generators contained in the aircraft (usually in the tail) that provide the aircraft with necessary energy during the time the aircraft is at the gate. Part of the generated energy is used for air conditioning. As an alternative at airports, the required energy can be supplied by ground-based equipment that gains significant net saving of carbon emissions. Fuel used by APUs is only a relatively small part of the total fuel use of an aircraft. British Airways estimates that the amount of fuel used by an APU is less than 1 % of the total fuel used by an aircraft.

**Taxi times**

The minimization of taxi times reduces the $CO_2$ emissions. The taxi phases in most of the cases can be optimised by reducing its times and distances. It's been noticed that the normal taxi time can vary between 8 and 26 minutes, which means that there is a big area of opportunities to reduce the $CO_2$ emissions. In the case of the freighter MD-11, for a load factor of 80%, the difference between making a taxi time of 8 and 26 minutes means 1,850 kg or about 5 % of $CO_2$ produced. This amount could be eliminated by having the appropriate systems for planning a shorter taxiing, by encouraging the control tower and the logistics personnel to make the shortest taxi routes for every operation. This taxi plan can be done in a more efficient way by designing appropriately from the beginning the airport, runways and the location of the gates and cargo terminals.

**Tankering**

Tankering is the extra quantity of fuel loaded into the airplane before the departure obeying to unexpected flight circumstances. The obvious reason for this is safety. The pilot decides this amount basing this decision on his experience, load of the aircraft, weather conditions, destination, etc. Other factors that can affect fuel costs and decisions on tankering include the following:

- Genuine high fuel costs because of expensive distribution infrastructure and local taxes
- Fuel availability at some remote airports
- Government-imposed fuel pricing
- Monopoly distribution of fuel, which can involve cross-subsidies from large to small airports and expensive manpower practices
- Concern over fuel quality (e.g., water content) at particular locations
- When limited aircraft turnaround time allows insufficient time for refuelling, an aircraft may have to tanker to minimize the risk of losing slots. Problems in this area are enhanced at congested airports, where there may be limitations in runway and/or terminal capacity.

This extra fuel implies extra weight for the aircraft, which requires more fuel. Estimates from British Airways suggest that additional fuel burn as a result of tankering is on the order of 0.5 percent of total aircraft fuel consumption.

**Aircraft**

One obvious factor that dramatically influence the $CO_2$ emission is the technical standard of the aircraft. The oldest models in use consumes about twice as much fuel per passenger km as the most modern once. This development is ongoing and the aviation industry is continuously working on increasing the fuel efficiency. The forecasts is that fuel efficiency will improve about 40-50% more by the year 2050 (IPCC, 1999).

**Flight altitude**

Even though the fuel consumption increases a couple of percent (4 % for a 1500 km flight in a Boeing 737-800) when changing altitude from 37000 ft to 31000 ft, the total global warming potential (GWP) is likely to decrease due to less influence of $NO_x$ in ozone perturbations. Klug et al. (1996) claims an 80 % increase in GWP for flying on this altitude due to larger influence by NOx and vapour.

**Aircraft Cruise Speed**

A number of fuel-conscious airlines developed the concept of a long-range cruise (LRC) speed schedule. LRC was introduced as a compromise between maximum speed and the speed that provides the highest mileage in terms of km per kg of fuel burned in cruise (maximum range cruise, or MRC speed), taking some account of costs associated with flight time. LRC is defined as the fastest speed at which cruise fuel mileage is 99 percent of fuel mileage at MRC. At the time LRC was introduced, it was not possible to fly at lower speeds, closer to MRC, because of the stability needs of the auto throttle and/or the autopilot. At speeds close to MRC, the auto throttle would continuously "hunt" which could give rise to an increase in fuel burn.

Figure 7.6 shows the relationship between the difference in block time and the difference in fuel consumption for various cruise speed schedules such as constant Mach number, LRC, MRC, or ECON for the Boeing 747-400. Block time is the time between engine start at the airport of origin and engine stop at the airport of destination and thus block fuel is the fuel burned in this time. The data presented suggest that reduction of fuel use by further speed optimisation is likely to be small.

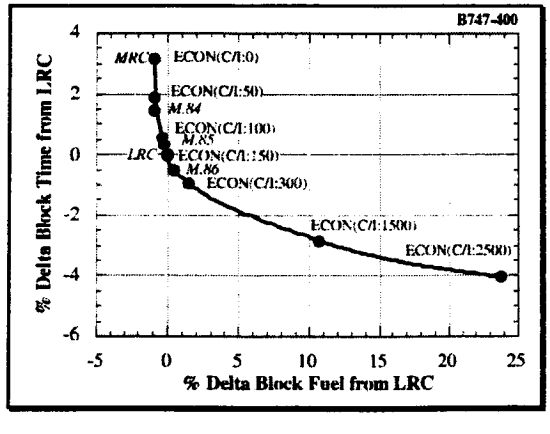



**Figure 2:** The effect of cruise speed dependent on block fuel and block time. ( ICAO, 1999).

**Improved Air Traffic Management**

There are congestion problems in some air routes. This occurs mainly because the distribution of the routes crossing the air spaces is not updated and some of them are "great-circle routes". It often happens that the aircrafts do not fly in the shortest way to the destination, because they are obliged to follow the assigned route. Previous studies have calculated that inefficiencies in European Air Traffic Control, resulting in circuitous routings and sub-optimal flight levels, cause an increase in fuel burn and hence impact on the environment of between 6-12 percent (AEA, 2001). The solution for an improved global air navigation infrastructure is often known as the concept of integrating communications, navigation, and surveillance/air traffic management (CNS/ATM) systems. ATM systems will therefore be developed and organized to overcome shortcomings previously discussed and to accommodate future growth.

| *Region* | *Fuel* | *$NO_x$* | *CO and HC* |
|---|---|---|---|
| Africa | 6 | 6 | 8-9 |
| Asia/Pacific | 6 | 6 | 17-19 |
| Europe | 10 | 10 | 14 |
| Latin America/Caribbean | 8 | 8 | 8 |
| Middle East | 4 | 4 | 4-5 |
| North America | 10 | 9 | 16 |
| **Global** | 9 | 8 | 15-16 |

**Table 2**: Projected fuel efficiency improvement in 2010 from accelerated implementation of CNS/ATM systems. (ICAO Journal, 2001).

The inefficiencies that exist in aircraft operations around the airport terminal mean that aircraft spend significantly longer on the ground with their engines running than is necessary. It is estimated that at Heathrow alone there could be a saving in fuel burn of 90,000 tonnes per annum through the introduction of advanced surface movement guidance and control system (A-SMGCS) and related ground management systems, such as improved surface management. This saving is roughly equivalent to one day of fuel burn across the whole ECAC area (Arthur D Little, 2000).

The projected fuel efficiency improvement in 2010 from accelerated implementation of CNS/ATM worldwide is predicted to be about 9 percent.

## Discussion

This paper aims at identifying cost effective measures to reduce the emissions of $CO_2$ in the air freight sector. It shows the results of an analysis of $CO_2$ emissions for a transport chain based on air freight. The calculations confirms that the most $CO_2$ emitting part of the transport chain is the actual flight and that it is in the take-off and climbing phases that most fuel are burned. It is also known that the technical development of aircraft implies a reduction in fuel consumption for each new generation of aircraft. The forecasts is that fuel efficiency will improve about 40-50% more by the year 2050. Thus, the aircraft manufacturers have an important role in this development.

There are also other strategies for mitigating the environmental impact of emissions from aviation that could achieve environmental benefits through reduced fuel burn. These strategies include: optimising aircraft speed, reducing additional weight, increasing the load factor, reducing

nonessential fuel on board, limiting the use of auxiliary power units, and reducing taxiing. Airlines are already under strong pressure to optimise these parameters, largely because of economic considerations and requirement within the industry to minimise operational costs. The potential reduction in fuel burn by further optimisation of these operational measures is in the range of 2–6 percent. Improvements in air traffic management could help to improve overall fuel efficiency by 6-12 percent. Other important factors identified are tankering and latest acceptance time which reduction potential are estimated to be about 5 % of the fuel consumption for a trip.

Most of the measures suggested are estimated to be comparably cost effective compared to the investments that are made to reduce the fuel efficiency of the aircraft and should be regarded as a complement. Reliable data on costs for introducing these measures are lacking due to e.g., confidentiality, and vague connections between the direct costs and reduced market attractiveness due to lowered customer service level. , these measures can be realised with better planning and improved information tools. Another barrier is the resistance against behavioural changes. These issues are suggested to be addressed in future research.

The analysis of the transport chain also shows the importance of choosing allocation method when emissions from a passenger aircraft with belly-freight shall be split between the passengers and the cargo. The result of a the study differs with a factor 3 between the different allocation methods.

## Acknowledgements

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LFV, 2001 – Luftfartsverket, Swedish Civil Aviation Administration, Norrköping, Sweden www.lfv.se

# AN APPLICATION OF THE METHODOLOGY FOR ASSESSMENT OF THE SUSTAINABILITY OF AIR TRANSPORT SYSTEM

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Abstract

An assessment and operationalization of the concept of sustainable air transport system is recognised as an important but complex research, operational and policy task. In the scope of the academic efforts to properly address the problem, this paper aims to assess the sustainability of air transport system. It particular, the paper describes the methodology for assessment of sustainability and its potential application. The methodology consists of the indicator systems, which relate to the air transport system operational, economic, social and environmental dimension of performance. The particular indicator systems are relevant for the particular actors such users (air travellers), air transport operators, aerospace manufacturers, local communities, governmental authorities at different levels (local, national, international), international air transport associations, pressure groups and public. In the scope of application of the methodology, the specific cases are selected to estimate the particular indicators, and thus to assess the system sustainability under given conditions.

Keywords: Air transport system, sustainability, dimensions of performance, indicator systems, assessment

# 1 INTRODUCTION

What is a sustainable system? According to the numerous definitions, this should be the system whose absolute consumption of the non-renewable energy resources (fossil fuels) and emission of greenhouse gases do not increase over time. According to these criteria, transport system can be considered as an unsustainable system (Daly, 1991; Whitelegg, 1993). However, since transport system also acts as a strong driving force of the economic development and social welfare, the above strict and direct approach to sustainability, particularly for the long-term development, needs to be redefined, at least by taking into account also the system positive effects in addition to the negative impacts. In such a context, sustainability of transport system could be considered as growth of the positive difference between the positive effects and negative impacts. Such development seems to be able to be achieved by establishing a balance (i.e., 'trade-off') between the system effects and impacts. However, the numerous conceptual and practical problems might emerge as barriers. One of the most important conceptual barriers seems to be a rather difficult consistent estimation of the system full effects mainly due to the diversity of approaches and methodologies. The main practical problem seems to lay in difficulty to globalise policies intended to promote the concept of sustainable development primarily due to the heterogeneity of performance of the system components and necessity for permanent compromising the interests of particular actors involved (ATAG, 2000: 2000a; DETR, 2000, 2001; EC, 1997; ECMT, 1998; Hewett and Foley, 2000; Levison et al., 1996 WCED, 1987).

This paper makes an academic effort in applying the methodology to assessment of the sustainability of air transport system (Janic, 2003). This methodology has been based on definition of the indicator systems of sustainability reflected the system operational, economic, social and the environmental dimension of performance[1] (FAA, 1996). The indicator systems for each dimension of performance contained the individual indicators and their measures have been defined with respect to sometimes the very confronted objectives of the various actors involved such as users (air travellers), air transport operators, aerospace manufacturers, local communities, governmental authorities at different levels (local, national, international), international air transport associations, pressure groups and public. By using the relevant inputs based on the structure of the indicator systems and particular measures, an assessment of the current level of sustainability of the air transport system with respect to particular indicators and measures is carried out (EC, 1999).

In addition to this introductory section, this paper consists of four sections. Section 2 describes the concept of sustainable air transport system. Section 3 deals with the sustainability indicators assumed to be relevant for particular actors. Section 4 contains estimation of the particular indicators for different cases thus illustrating an application of the methodology. The last section contains some conclusions.

[1] This is an analogous definition to the definition of sustainable society, which is supposed to possess three essential dimensions of performance: economic, social, and environmental (Agenda 21 of the UNCED (United Nations Conference on Environment and Development) Conference in Rio de Janeiro, Brasil/1992).

# 2 THE CONCEPT OF SUSTAINABLE AIR TRANSPORT SYSTEM

## 2.1 Basic principles of sustainability

In the light of the refined definition of sustainability, air transport system is considered to be sustainable if the net benefits of its operations increase with increasing of the system output either in the absolute (total) or relative terms (per unit of output). The net benefits are represented as the sum of differences between the positive effects ("benefits") and the negative impacts ("costs") at different geographical scales such as global (intercontinental), regional (national/continental), and local (community) scale (INFRAS, 2000).

### *2.1.1 Sustainability at global scale*

At global scale, growth of economy and air transport demand have been strongly driven by each other with the evident negative consequences in terms of the absolute increase in energy (fossil fuels) consumption and global emission of greenhouse gases. In such a context, several options (scenarios) is thought to be useful to drive the system towards sustainable development, i.e., to setting up of trade-off between the positive effects and the negative impacts, as follows (Janic, 2003):

- *Constraining the system growth at global scale*, which would include setting up an absolute limit to growth of the air transport demand and consequently to growth of the associated negative impacts;
- *Setting up a cap on the impacts*, which would limit the system energy consumption, associated air pollution, and thus indirectly its growth (Hewett and Foley, 2000);
- *Decoupling growth of the system demand* and *the economic growth*, which would include weakening of the strong links between the air transport demand and GDP (Gross Domestic Product). This has seemed to be able to be carried out by stimulating people to change their habits in the long-term (EC, 1999); and
- *Trading-off between global effects and impacts,* which as a compromise scenario would provide mechanisms for the faster growth of the system long-term global positive effects than the negative impacts.

### *2.1.2 Sustainability at regional scale*

At a regional (national, continental) scale, particularly in the U.S. and Western Europe, the growth of air transport demand been additionally driven by local forces such as liberalisation of air transport market(s), increasing of the system productivity and diminishing of airfares. Such growth has been confronted with the limited capacity of airports and ATM (Air Traffic Management)/ATC (Air Traffic Control), which has increased congestion and ultimately compromised the expected efficiency and effectiveness of service. Under such circumstances, a balance between the system growth and the associated negative impacts seems to be able to be achieved by three scenarios as follows (Janic, 2003):

- *Affecting regional demand-driving forces*, which would, as a controversial scenario, include affecting the factors influencing market liberalisation and competition, productivity, and airfares in a way to discourage further growth of air transport demand (Boeing, 2001).

- *Constraining the infrastructure expansion,* which as "do nothing" scenario in terms of constraining the further expansion of the air transport infrastructure under conditions of growing demand could lead to a widespread and severe deterioration of the efficiency and effectiveness of service. In turn, such development might deter both existing and prospective users (EUROCONTROL, 2001).
- *More efficient utilisation of the available infrastructure*, which could lead to improvements of utilisation of existing airport and ATM/ATC infrastructure by using innovative technologies and operational procedures, modification(s) of the airline operational practice, and co-operation with other transport modes (particularly railways) (Arthur, 2000).

*2.1.3 Sustainability at local scale*

At local scale, the positive effects and the negative impacts of growth of individual airports need to be balanced according to the following scenarios (Janic, 2003):

- *Constraining the airport growth*, which would include constraining the available land for an airport physical expansion, which in turn would compromise its further growth[2].
- *Management of the airport growth*, which, at an airport, would include provision of the higher rates of increase of the total local benefits than the costs of the associated impacts (BA, 2001).

## 2.2 Dimensions of the system performance

Definition of the indicator systems of sustainability of the air transport system can be carried out with respect to the operational, economic, social, and environmental dimension of performance[3]. The particular dimensions of performance have been dependent on each other, but the operational dimension has mostly influenced the other three. Figure 1 illustrates a generic scheme of these relationships (Janic, 2003).

The operational dimension is the basic one, which relates to the characteristics of the system demand, capacity, effectiveness, safety and security of service (Janic, 2003).

The economic dimension relates to the system operating revenues, costs and productivity (Hooper and Hensher, 1997).

The social dimension relates to the social effects such as the system direct and indirect contribution to employment and GDP at local and regional scale (Button and Stough, 1998; DETR, 1999; 2000). In addition, contribution to globalisation and internalisation of business and leisure activities (international trade, investments, tourism) could be taken into account.

The environmental dimension relates to the system physical impacts on the people's health and environment in terms of the local (airport) and global (airspace) air pollution, airport noise, aircraft accidents, congestion, generation of waste and land use (Janic, 1999).

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[2] For the first time, at Amsterdam Schiphol airport the government has limited by law the maximum annual number of aircraft movements aiming at controlling the noise. Consequently, in 1998 the maximum number of aircraft movements has been restricted to 380 000 with possible annual increase of 20000 until 2003 (Boeing, 2001; Offerman and Bakker, 1998).

[3] Some studies consider only three dimensions of air transport system performance: economic social and environmental (INFRAS, 2000).

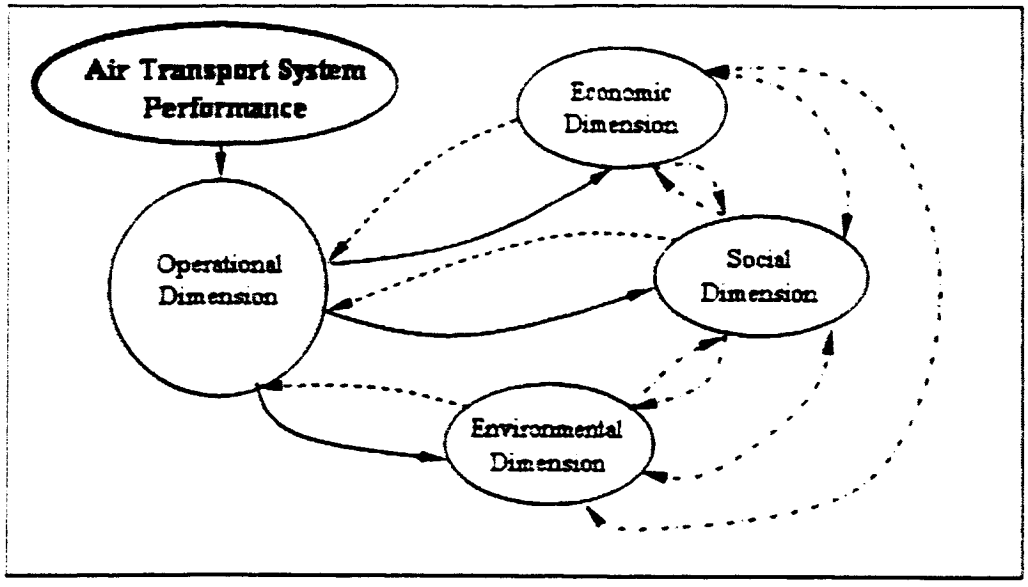


**Figure 1** Dimensions of performance of air transport system and their linkage

2.3 The actors, their objectives and preferences

According to the structure of air transport system, the following main actors may be involved in dealing with the sustainability as follows (ATAG, 2000; INFRAS, 2000):

- *Users of services* such as air travellers and shippers of freight and mail constituting the air transport demand;
- *Air transport operators* providing the system services by using the related infrastructure, facilities and equipment such as airports, Air Traffic Management (ATM)/ Air Traffic Control (ATC), and airlines;
- *Aerospace manufacturers* producing the aircraft, ATM/ATC, and airport facilities and equipment;
- *Local community members* (population) living in the vicinity of airports;
- *The governmental bodies* playing the role in the institutional regulation of the system operations at local (community) and central (national) level;
- *Aviation organisations* co-ordinating the system development at global (international) scale;
- *Lobbies and pressure groups* articulating the interests of people who may be for or against an expansion of the system infrastructure; and
- *Public* temporarily interesting in the specific aspects of the system operations.

Figure 2 shows a simplified structure of the air transport system used for development of the indicator systems as the methodology for assessment of its sustainability. Sustainability of the air transport system may have different meaning and contents for the particular actors, which are summarised as follows:

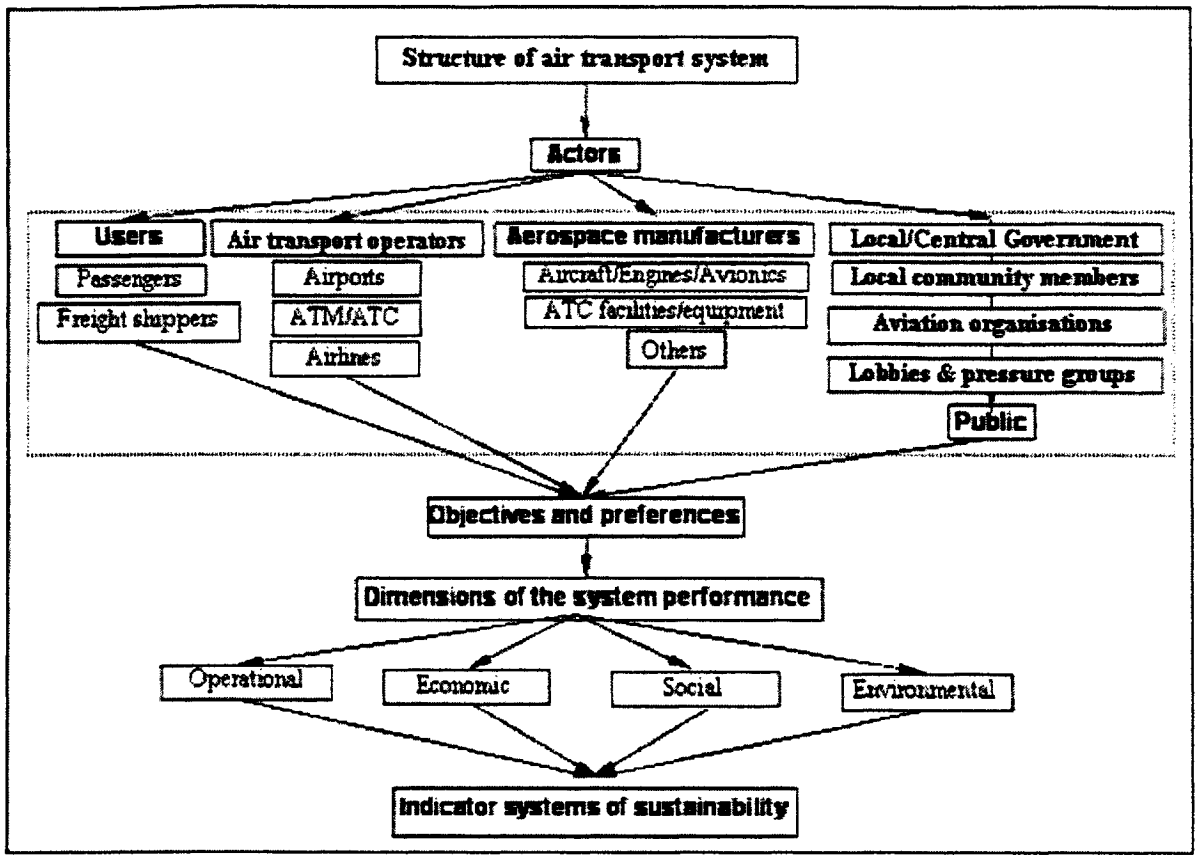


**Figure 2** Simplified structure of air transport system used for assessment of sustainability

The *users – air travellers* and *shippers of freight* and *mail* usually prefer frequent, easily accessible, low cost, punctual, reliable, safe and secure services.

The *air transport operators* prefer services according to their business objectives in terms of the profitability, safety and security on the one hand, and the users' preferences on the other.

The *aerospace manufacturers* prefer smooth selling of their reliable, safe, and profitable products to the system operators.

*Local community members* usually tend to maximise the benefits and minimise the costs of air transport system at their local scale. The employment opportunity and use of efficient air connections to other distant communities (regions) can be considered as the obvious benefits. The costs are regarded as exposure to the airport noise, air pollution, and risk of injury, loss of life and damage of property due to the aircraft accidents.

*Local* and *central government(s)* are mostly interested in the system overall benefits and externalities. Direct benefits may include the system contribution to the local and national employment and GDP. Indirect benefits may embrace contributions to internalisation and globalisation of manufacturing, trade, investments and tourism. Externalities may be of interest while creating local and global policies to protect the people's health and environment.

*International aviation organisations* such as ICAO, IATA, ECAC, AEA and ACI provide the framework and guidelines for co-ordinated (sustainable?) development of the system at both regional (national) and global (international) scale.
*Different lobbies and pressure groups* organise campaigns against global harmful effects of the polluting systems on the people health and environment. In such scope, they also intend to prevent further contribution of the air transport to global warming by strong opposition, sometimes together with local community people to the physical expansion of the system infrastructure - airports.
*Public* uses media such as radio, TV, Internet and newspapers to get information about the system. This interest is strengthening in the cases of launching innovations (aircraft, airports), severe disruptions of services and air accidents, and changes of airfares. In general, the information about the system should be available to public at any time.

# 3 THE INDICATOR SYSTEMS OF SUSTAINABILITY

## 3.1 General

The indicator systems of sustainability of air transport system have been defined to measure the effects ("benefits") and impacts ("costs") in either absolute or relative monetary or non-monetary terms, as functions of the relevant system output (Janic, 2003). In such a context, the system has been assumed to be sustainable if the measure of an indicator reflected the relative effects has increased and the other one reflected the relative impacts decreased (or been constant) with increasing of the relevant system output, and vice versa. Figure 3 shows a generic scheme[4].

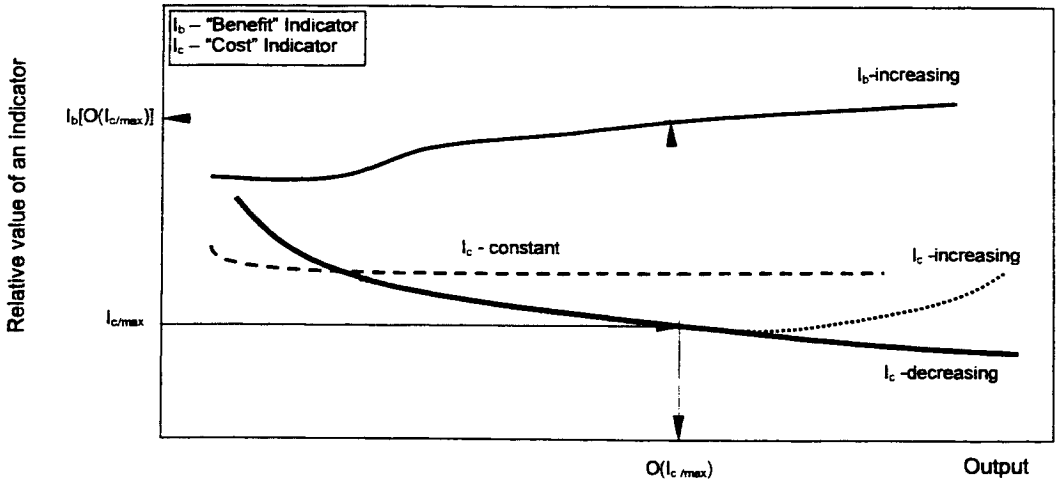


**Figure 3** Relationships between the sustainability indicators and the system output

[4] Setting up a limit on the particular indicator may have two-fold effect. For example, if the cost indicator is limited to $I_{c/max}$, the output will be able to rise maximally to $O(I_{c/max})$. Such constrained output will affect a benefit indicator, which will be allowed to rise maximally to $I_b[O(I_{c/max})]$. Consequently, setting up the criteria on indicators should always include balancing (i.e., trading-off) between the effects and impacts.

## 3.2 Structure of the indicator systems

Different actors might use different indicator systems for assessment of the system sustainability with respect to the particular dimensions of the system performance and their specific preferences. The indicator systems consisted of the individual indicators and their measures have been valid for given period of time (day, month, year) (Janic (2003).

### *3.2.1 Indicators for users – air travellers*

The indicator system for users-air travellers have consisted of eight individual indicators related to the airports and airlines operated at different scales as follows:

*i) Operational indicators*

The indicators of the operational dimension of performance have been as follows:

- *Punctuality* of service has been measured by the probability that a flight has been on time, and the average delay per flight[5] (Headley and Bowen, 1992; USDT, 2001). Users have usually preferred the former measure to be as high as possible and the latter one as low as possible with increasing of the number of flights.
- *Reliability* of service has been measured as the ratio between the realised and the total number of flights (USDT, 2001). The measure has been preferred to be as high as possible and to increase with increasing of the number of flights.
- *Ratio of lost/damaged baggage* has been expressed as the proportion of the lost (or damaged) baggage compared to the total number of passengers served. This measure has been preferred to be as low as possible and to decrease with increasing of the number of passengers.
- *Safety* has been measured as the ratio of the number of deaths (or injuries) per unit of output - RPK (RPM) (RPK – Revenue Passenger Kilometer; RPM – Revenue Passenger Mile). The users have always preferred this measure to be as low as possible and to decrease with increasing of RPK (RPM).
- *Security* has been measured as the ratio between the number of detected illegal dangerous devices and the total number of passengers screened. It has been preferred to be as low as possible and to decrease with increasing of the number of passengers.

*ii) Economic indicators*

The indicators of the economic dimension of performance have been as follows:

- *Economic convenience of service* has measured by the average airfare per passenger preferred by users to be as low as possible[6].

*iii) Social indicators*

The indicators of the social dimension of performance have been as follows:

- *Spatial convenience of service* has been measured by the number and diversity of destinations and flights at an airport with respect to type of destination, connectivity (non-stop, one-stop or multi-stop) and trip purpose (business, leisure). In general, users prefer this measure to be as high as possible.

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[5] Usually, delays are categorized as the arrival and departure delays, which may be shorter or longer than 15 minutes (EUROCONTROL, 2001a; USDT, 2001).

[6] Some airfares charged by low-cost air carriers in Europe and the US may represent the exceptions from this general rule.

*iv) Environmental indicators*

The indicators of the environmental dimension of performance have been as follows:

- *Comfort* and *healthiness* at airports have been measured by the number of passengers per unit of the available space and the average queuing time (Hooper and Hensher, 1997; Janic, 2001). Configuration and size of seats in the economy class[7] and the quantity of fresh air delivered to the passenger cabin per unit of time have been used to measure the passenger comfort while onboard. The airport measures have been preferred to be as low as possible and to decline with increasing of the number of passengers served. The measures of comfort and healthiness while onboard have been preferred to be as high as possible.

*3.2.2 The indicator system for airports*

The indicator system for airports has consisted of eleven indicators related to an or a set of airports in a given region (Janic, 2003).

*i) Operational indicators*

The indicators of the operational dimension of performance have been as follows:

- *Demand* has expressed the number of passengers and the number of Air Transport Movements (ATM)[8], which has been preferred to be as great as possible within the available capacity.
- *Capacity* has been measured as the maximum number of passengers and maximum number of ATM. Both measures have been preferred to be as high as possible and to increase in line with growing demand (Janic, 2001).
- *Quality of service* has been measured by the average delay per ATM or per passenger occurred whenever the demand has exceeded the capacity. The measure has been preferred to be as low as possible and to decrease with increasing of demand (Janic, 2001).
- *Flexibility of using the available capacity* has measured by the ratio between the number of substituted flights by other transport modes and the total number of flights[9]. This ratio has been preferred to be as higher as possible and to increase with increasing of the number of flights.

*ii) Economic indicators*

The indicators of the economic dimension of performance have been as follows:

- *Profitability* has been measured by the operating profits (the difference between operating revenues and operating costs) per unit of the airport output–ATM or passenger[10] (Doganis, 1992). This measure has been preferred to be as high as possible and to increase with increasing of the output.

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[7] Configuration of the economy class seats at long haul flights has recently emerged as a matter of concern due to cases of passenger deaths caused by DVD (Deep in Vein Disease).

[8] An Air Transport Movement (ATM) is either arrival or departure.

[9] For example, three European 'super' hubs, Frankfurt, Paris CDG and Amsterdam Schiphol are connected to High Sped Rail Network. Partial substitution of short-haul flights has already taken place there (EC, 1998; HA, 1999; IFRAS, 2000). If the air-rail substitution were carried out without filling in freed slots by long haul flights, congestion and associated local and global air pollution, and noise would be reduced. Under such circumstances, this indicator could be classified as an environmental indicator.

[10] In many cases, the common unit called 'Workload Unit' or 'WLU' has been used as an equivalent for one passenger or 100 kg of baggage (Doganis, 1992)

- *Labour productivity* has been expressed by the number of ATM, passengers or WLU per employee (Doganis, 1992; Hooper and Hensher, 1997). This measure has been preferred to be as high as possible and to increase with increasing of the number of employees.

*iii) Social indicators*

The indicators of the social dimension of performance have not been identified.

*iv) Environmental indicators*

The indicators of the environmental dimension of performance have been as follows:

- *Energy inefficiency* has been measured by the quantity of energy consumed per unit of the airport output – ATM or a passenger. This measure has preferred to be as low as possible and to decrease with increasing of the output.
- *Noise efficiency* has been expressed by the area in square kilometres determined by the equivalent noise level in decibels - dB (A) (DETR, 2000; 2001). This indicator has been preferred to be as small as possible and to diminish with increasing of the number of ATM.
- *Air pollution efficiency* has been measured by the air pollutants per an event - LTO[11] cycle (EPA, 1999; ICAO, 1993a). This measure has been preferred to be as low as possible and to decrease with increasing of the number of LTO cycles.
- *Waste efficiency* has been measured by the quantity of waste per unit of the airport output – ATM or passenger (BA, 2001). The measure has been preferred to be as low as possible and to decrease with increasing of the airport output.
- *Land use efficiency* has been measured in terms of the area of land used for accommodating air transport demand. The measure has been preferred to be as low as possible and to increase with increasing of the volume of demand.

*3.2.3 The indicator system for Air Traffic Management (ATM)/Air Traffic Control (ATC)*

The indicator system for Air Traffic Management (ATM)/Air Traffic Control (ATC) have consisted of eight indicators, which might be quantified for a part (ATM/ATC sector) or for the whole system (airspace of a country or a wider region – continent) (Janic, 2003).

*i) Operational indicators*

The indicators of the operational dimension of performance have been as follows:

- *Demand* has been measured as the number of flights demanded to pass through a given ATM/ATC airspace (Janic, 2001). This measure has been preferred to be as great as possible.
- *Capacity* has been measured by the maximum number of flights served in a given airspace per unit of time (Janic, 2001). This indicator has been preferred to be as great as possible and to increase with growing demand.
- *Safety* has been measured by the number of aircraft accidents or the number of Near Midair Collisions (NMAC) per unit of the ATM/ATC output – controlled flight. Both measures have been preferred to be as low as possible and to decrease with increasing of the number of flights.

[11] ICAO has recommended LTO cycle – Landing/Take-Off cycle as a standardised format for quantifying air pollution at airports (International Civil Aviation Organisation, 1993a)

- *Punctuality of service* has been measured by the proportion of flights being on time and the average delay per delayed flight due to the ATM/ATC restrictions. While former measure has been preferred to be as high as possible and to increase, the latter measure has been preferred to be as lower as possible and to decrease, with increasing of the number of flights.

*ii) Economic indicators*

The indicators of the economic dimension of performance have been as follows:

- *Cost efficiency*[12] has been measured by the average cost per unit of output – controlled flight. The measure has been preferred to be as low as possible and to decrease with increasing of the number of flights (Janic, 2001).
- *Labour productivity* has been reflected the number of controlled flights per an employee. This measure has been preferred to be as high as possible and to increase with increasing of the number of employees.

*iii) Social indicators*

The indicators of the social dimension of performance have not been identified.

*iv) Environmental indicators*

The indicators of the environmental dimension of performance have been as follows:

- *Energy efficiency* has been measured by the extra fuel consumption per flight due to deviations from the prescribed (fuel-optimal) trajectories dictated by the ATM/ATC. It has been preferred to be as low as possible and to decrease with increasing of the number of flights.
- *Air pollution efficiency* has been measured by the average quantity of pollutants per flight caused by the extra fuel consumption. The indicator has been preferred to be as low as possible and to decrease with increasing of the number of flights.

### *3.2.4 The indicator system for airlines*

The indicator system for airlines has embraced eleven indicators, which could be quantified for an individual airline, airline alliance or the whole airline industry of a given region (country or continent) (Janic, 2003).

*i) Operational indicators*

- *Airline size* has been expressed by the volume of RTK or RTM (RTK (RTM)–Revenue Ton-Kilometre (Mile)), the number of flights, the number of passengers and/or the size of the resources used in terms of the number of aircraft and staff (Janic, 2001). The above measures have been preferred to be as great as possible and to increase over time and under conditions of sufficient demand.
- *Load factor* has been measured as the ratio between the total RTK (RTM) - Revenue Ton-Kilometre (Mile) and ATM (ATK)–Available Ton-Kilometre (Mile). This measure has been preferred to be as great as possible and to increase with increasing of the airline output (Janic, 2001).

[12] The 'cost' is considered to be more relevant indicator than the 'profitability' because the most ATM/ATC providers charge their services on the cost-recovery principle. For example, EUROCONTROL member States and ATM providers from Canada, Australia, New Zealand, South Africa, etc. fully recover their costs by charges (INFRAS, 2000).

- *Punctuality, reliability* and *safety* of service have been measured and preferred analogously as that of users (Janic, 2001).

*ii) Economic indicators*

The indicators of the economic dimension of performance have been as follows:

- *Profitability* has been measured by the average profits (difference between the operating revenues and costs) per unit of output – RTK (RTM). This measure has been preferred to be as great as possible and to increase with increasing of the airline output.
- *Labour productivity* has been measured by the average quantity of output - RTK (RTM) - per employee. The preference for this measure has been to be as great as possible and to increase with increasing of the number of employees.

*iii) Social indicators*

None of these indicators has been identified.

*iv) Environmental indicators*

The indicators of the environmental dimension of performance have been as follows:

- *Energy* and *air pollution efficiency* have been measured by the average quantity of fuel and associated air pollution, respectively, per unit of output – RTK (RTM), distance flown or the number of flying hour). Both measures have been preferred to be as low as possible and to decrease with increasing of output.
- *Noise efficiency* has been measured by the proportion of the aircraft of Stage 3 and 4 in an airline fleet. This measure has been preferred to be as great as possible and to increase with expansion of the airline fleet[13] (BA, 2001; ICAO, 1993b).
- *Waste efficiency* has been measured by an average quantity of waste per unit of the airline output – RTK (RTM). This measure has preferred to be as low as possible and to diminish with growing of the airline output (BA, 2001).

*3.2.5 The indicator system for aerospace manufacturers*

The indicator system of the airspace manufacturers has consisted of eight indicators as follows (Janic, 2003).

*i) Operational indicators*

The indicators of the operational dimension of performance have been as follows:

- *Aircraft innovations* have been measured by technical productivity the cost efficiency (RAS, 2001). The former measure preferred to be as high as possible has been expressed as the product between the aircraft speed and capacity product (ton-kilometres (miles) per hour). The latter preferred to be as low as possible has been expressed by the average operating cost per unit of capacity–ATK (ATM) (ATK–Available Ton Kilometre; ATM-Available Ton Mile) (Arthur, 2000; Janic, 2001).
- *Innovations* of *ATM/ATC* and *airport facilities* have been measured by the cumulative navigational error of an aircraft position, and the capacity of facilities used for processing demand at airports, respectively. The former measure has been preferred to

[13] Once an airline fleet is completely modernized by replacing all aircraft of Stage 2 by the aircraft of noise category 3 and 4, this indicator will become irrelevant.

be as small as possible and the latter one as high as possible (Arthur, 2000; Janic, 2001).

- *Reliability of structures* has been measured by the rate of failures of the particular components per unit of time. Due to the safety and operational reasons, this measure, has been preferred to be as high as possible.

*ii) Economic indicators*

The indicators of the economic dimension of performance have been as follows:

- *Profitability* has been measured by the average operating profits (the difference between operating revenues and costs) per unit sold. This measure has been preferred to be as great as possible and to increase with increasing of the number of units.
- *Labour productivity* has been measured by the average number of units produced per employee. The measure has been preferred to increase with increasing of the total number of employees.

*iii) Social indicators*

The indicators of the social dimension of performance have not been identified.

*iv) Environmental indicators*

The of the environmental dimension of performance have been as follows:

- *Energy, air pollution* and *noise efficiency* have been measured by the absolute or relative decrease in the fuel consumption, air pollution or noise per unit of engine power or the aircraft operating weight. These measures have been are preferred to be as low as possible and to decrease with increasing of the engine power and/or aircraft operating weight.

*3.2.6 The indicator system for local community*

The indicator system for the local community has consisted of four indicators of sustainability as follows (Janic, 2003):

*i) Operational indicators*

The indicator system of the operational dimension of performance has not been identified.

*ii) Economic indicators*

The indicator system of the economic dimension of performance has not been identified.

*iii) Social indicators*

The indicator system of the social dimension of performance has comprised only one indicator as follows:

- *Social welfare* has been measured by the ratio between the number of people employed by air transport system and the total number of employed people within the local community. This measure has been preferred to be as high as possible and to increase with increasing of employment within the local community (DETR, 1999).

*iv) Environmental indicators*

The indicator system of the environmental dimension of performance has consisted of three

indicators as follows:

- *Noise disturbance* has been measured by the total number of noise events – ATM - during given period of time (day, month, year) and by the \number of complaints per noise event - ATM. Both measures have been preferred to be as low as possible and to decrease with increasing of the number of ATM.
- *Air pollution* has been measured as the ratio between the quantity of air pollutants from air transport system and the total air pollution from all other local sources. This indicator has been preferred to be as low as possible and to decrease with increasing of the total air pollution.
- *Safety* has been measured by the number of aircraft accidents per ATM, which has affected the local community people in terms of damaging their property, injuries or loss of life. This measure has been preferred to be as low as possible and to decrease with increasing of the number of ATM.

*3.2.7 The indicator system for (local and central) governments*

The indicator system for the local and central government has consisted of seven indicators as follows (Janic, 2003):

*i) Operational indicators*

The indicators of the operational performance have not been identified.

*ii) Economic indicators*

The indicators of the economic dimension of performance have been as follows:

- *Economic welfare* has been measured by the proportion of GDP of air transport sector in the total GDP. This measure has been preferred to be as great as possible and to increase with increasing of the total GDP.
- *Internalisation/globalization* has been measured by the proportion of trade in terms of the volume and/or value of export and import by air transport in the total regional (country) trade, and by the ratio between the number of air trips and total number of trips (business/leisure) in a given region (country). These measures have been preferred to be as great as possible and to increase with increasing of the volume (value) of trade and the total number of trips, respectively.
- *Externalities* have been measured by the average expense per unit of the system output– RPK (RPM) due to either preventing or remedying the particular impacts such as noise, air pollution, air incidents/accidents, and sometimes congestion (DETR, 2001; EC, 1997; Janic, 1999; Levison et. al, 1996; Yang-Lu, 2000). This measure has been preferred to be as low as possible and to decrease with increasing of the system output.

*iii) Social indicators*

The indicators of the social dimension of performance have been as follows:

- *Overall social welfare* has been measured as the ratio between the number of employees within air transport sector and the total number of employees in a region (country). This measure has been preferred to be as high as possible and to increase with increasing of the total employment.

*iv) Environmental indicators*

The indicators of the environmental dimension of performance have been as follows:

- *Global energy efficiency* has been measured by the average amount of fuel consumed per unit of the system output–RTK (RTM). This measure has been preferred to be as low as possible and to decrease with increasing of the system output.
- *Global noise disturbance* has been measured by the total number of people exposed to the air transport noise during given period of time (year). The measure has been preferred to be as low as possible and to decrease over time.
- *Global air pollution* has been measured by the total emissions of air pollutants per unit of the system output – RTK (RTM) (EC, 1998b). This measure has been preferred to be as low as possible and to diminish with increasing of the system output.
- *Global land use* has been measured as the ratio between the land used for air transport infrastructure and the total land used for infrastructure of the whole transport system of a given region (country). This measure has been preferred to be as low as possible and to decrease with increasing of the area of land acquired for transport infrastructure.

## 4 AN APPLICATION OF THE METHODOLOGY

Fifty-eight indicators and sixty-eight measures have been defined in the scope of the indicator systems corresponded to seven groups of actors – users-air travellers, the system operators – airports, airlines and ATM/ATC, airspace manufacturers, local community members, and local and central government. For particular actors twenty-six selected indicators are estimated in order to illustrate existence of the sustainability of air transport system. Their list is given in Table 1.

Table 1: Indicators estimated for assessment of the sustainability of air transport system

| *Actor* | *Dimension of the system performance* | *Indicator* |
|---|---|---|
| Users | • Operational | o *Punctuality*<br>o *Reliability*<br>o *Lost & damaged baggage*<br>o *Security* |
| | • Economic | o *Economic convenience* |
| | • Social | o ---- |
| | • Environmental | o ---- |
| Airports | • Operational | o ---- |
| | • Economic | o *Profitability*<br>o *Labour productivity* |
| | • Social | o ---- |
| | • Environmental | o *Air pollution efficiency*<br>o *Noise efficiency*<br>o *Waste efficiency* |
| ATM/ATC | • Operational | o *Safety* |
| | • Economic | o ---- |
| | • Social | o ---- |

| | | |
|---|---|---|
| | • Environmental | ○ ----- |
| Airlines | • Operational<br>• Economic<br>• Social<br>• Environmental | ○ *Punctuality*<br>○ *Reliability*<br>○ *Productivity*<br>○ ----<br>○ *Energy (fuel) efficiency* |
| Aerospace manufacturers | • Operational<br>• Economic<br>• Social<br>• Environmental | ○ *Technical productivity*<br>○ *Efficiency*<br>○ ----<br>○ ----<br>○ *Fuel efficiency*<br>○ *Noise efficiency* |
| Local community members | • Operational<br>• Economic<br>• Social<br>• Environmental | ○ ----<br>○ ----<br>○ ----<br>○ *Noise disturbance* |
| Governments | • Operational<br>• Economic<br>• Social<br>• Environmental | ○ ----<br>○ *Economic welfare*<br>○ *Internalisation/Globalisation*<br>○ *Overall social welfare*<br>○ *Global energy efficiency Global noise disturbance*<br>○ *Global air pollution* |

Data for estimating the particular indicators and their measures are extracted from different secondary sources. The results are given in Figure 4, 5, 6, 7, 8, 9 and 10.

i) Users

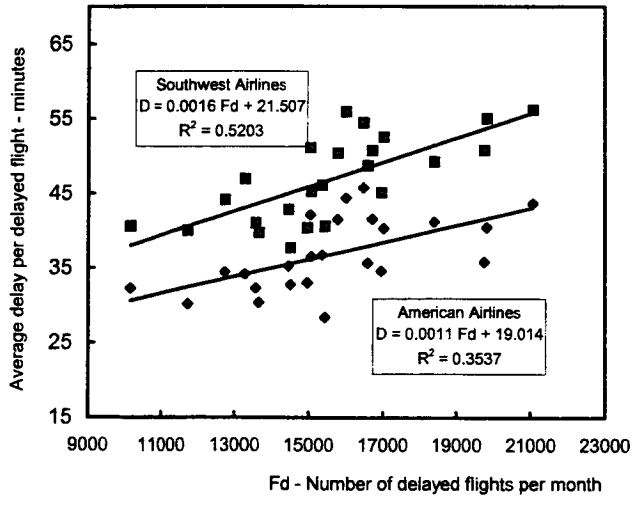


**Figure 4a** Punctuality of some U.S. airlines: period 1999-2000 (Compiled from USDT, 2001)

Figure 4a illustrates punctuality of American and Southwest Airlines (U.S). As can be seen, at both airlines the average delay per delayed flight has increased with increasing of the number of delayed flights. As well, the average delay of a Southwest flight has been longer than the average delay of an American flight, independently on the number flights carried out. Consequently, users might have better perception of punctuality of American than Southwest Airlines, but in general, they both have been unsustainable according to this indicator.

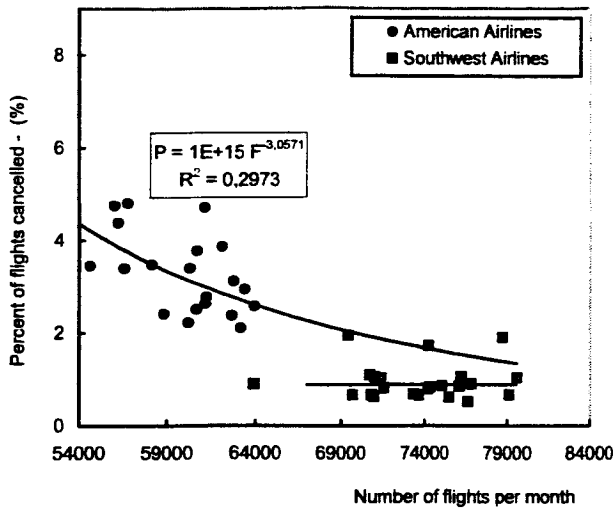


**Figure 4b** Reliability of some U.S. airlines: period 1999-2000 (Compiled from USDT, 2001)

Figure 4b illustrates reliability of two U.S. airlines, American and Southwest, as proportion of the cancelled flights dependent on the total number of flights carried out per month. As can be seen, in given example, at American this proportion has varied between 2% and 6% and generally decreased with increasing of the number of flights. At Southwest, it has varied between 0.5% and 2% and has been nearly constant with increasing of the number of flights. As well, Southwest has performed greater number of flights than American. From the above example, it seems that the airlines with a greater number of flights have also tend to provide a higher reliability of services, which according to the users' perception have made them more sustainable.

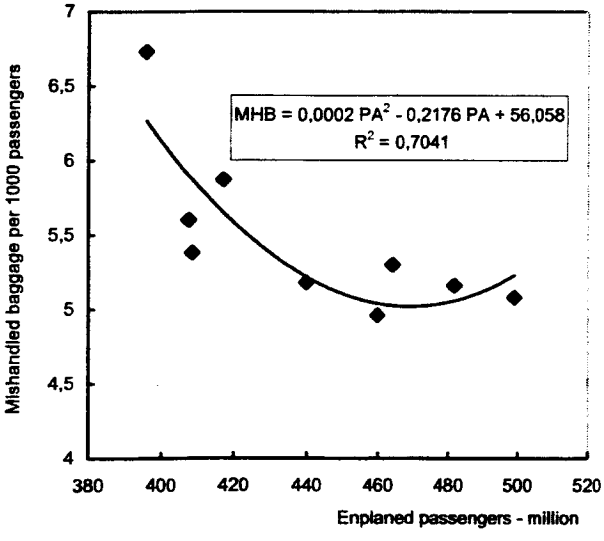


**Figure 4c** Llost and damaged (mishandled) baggage at U.S. domestic schedule services: period 1990–1999 (Compiled from USDT, 2001)

Figure 4c illustrates a ratio of mishandled (lost and damaged) baggage in dependence on the total number of domestic passengers served at the U.S. airports. As can be seen, this ratio has varied between 5 and 6.5% and decreased with increasing of the number of passengers up to about 460 million. Above this number, the ratio has started to increase with increasing of the number of passengers, which has indicated worsening of the performance. From the users' prospective, according to the variations of this indicator, the system has been sustainable under condition of rising of the number of passengers to a certain limit, and unsustainable beyond that limit.

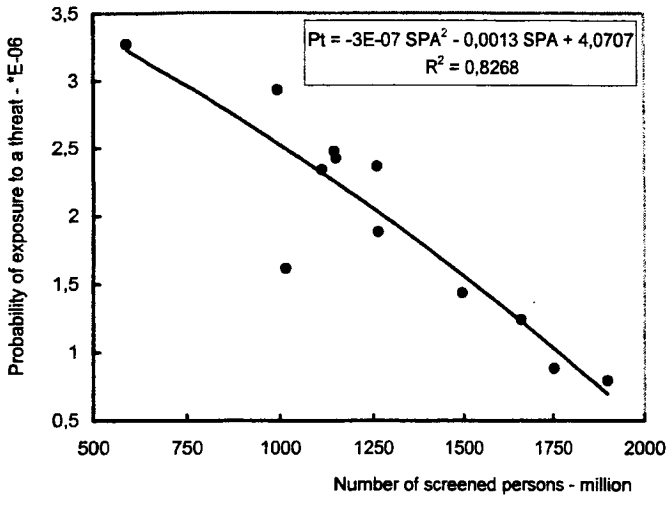


**Figure 4d** Security at U.S. airports – period 1980–1999 (Compiled from BTS, 2001)

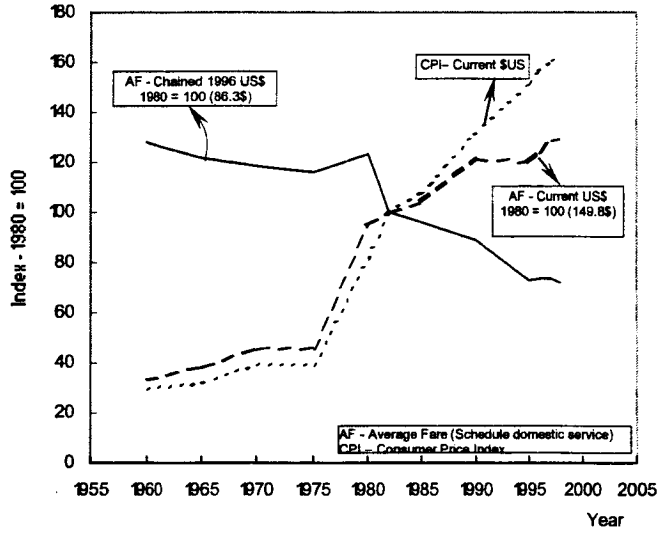


**Figure 4e** Economic convenience of the U.S. air transport system (Compiled from BTS, 2001)

Figure 4d illustrates security at the U.S airports expressed by the probability of being exposed to the threat of illegally carried dangerous devices in dependence on the number of passengers screened per year. As can be seen, this probability has decreased with increasing of the number of screened passengers. This has indicated the system long-term sustainability with respect to this indicator. Nevertheless, one has to be cautious with this measure since also the very low risk has hidden a virtual threat with a potential to materialize into the events with serious consequences such as, for example, September 11 (2001) terrorist attack on the U.S.

Figure 4e illustrates economic convenience of air transport services for users of the U.S. air transport system expressed by changing of the average airfares and Consumer Price Index (CPI) during the observed period. As can be seen, two periods have been evident: first, it has been the period between 1960 and 1982 when the index of airfares had been above the index of CPI; second, it ahs been the period from 1983 on, when the index of CPI has been below than that of airfares. The main forces of such change have consisted of the positive developments in the U.S. aviation market after deregulation (1978) on the one hand and an overall socio-economic progress on the other. In addition, in an absolute sense, airfares have been more or less permanently decreasing, particularly after the year 1983, which might illustrate the long-term system sustainability according to this indicator.

ii) Airports

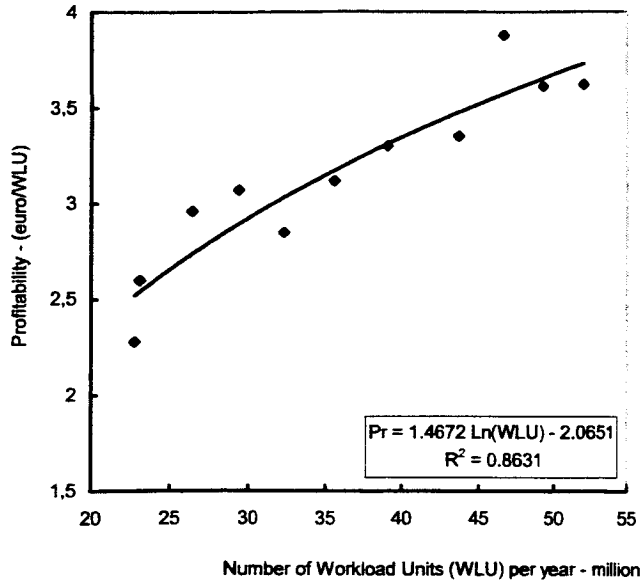


**Figure 5a** Profitability of Amsterdam Schiphol airport: period 1990-2000 (Compiled from Schiphol Group, 2000)

Figure 5a illustrates profitability of Amsterdam Schiphol airport (Netherlands). The profitability as the difference between revenues and costs in terms of EURO per WLU (Work Load Unit) has been related to the total annual number of WLU accommodated at the airport. As can be seen, this profitability has increased with increasing of the number of WLU at a decreasing rate. In given example, existence of the long-term airport sustainability has been indicative with respect to this indicator.

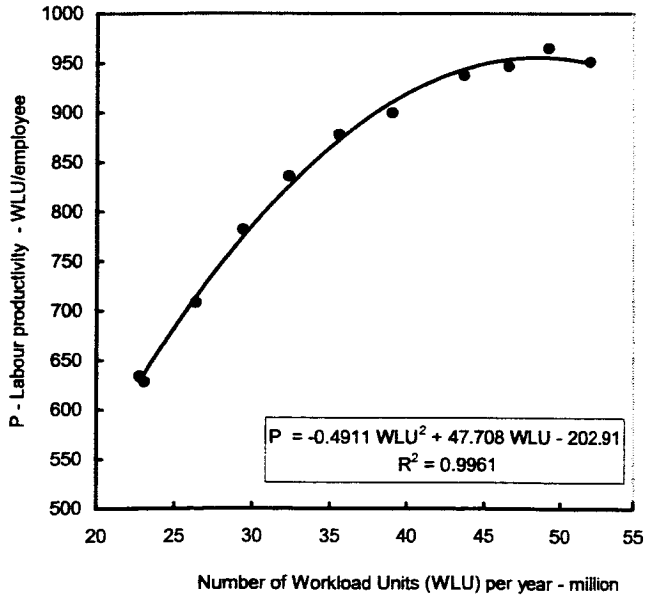


**Figure 5b** Labour productivity at Amsterdam Schiphol airport – period 1990-2000 (Compiled from Schiphol Group, 2000)

Figure 5b illustrates labor productivity at Amsterdam Schiphol airport (Netherlands). This productivity in terms of the number of WLU per employee has been related to the total number of WLU accommodated at the airport per year.

As can be seen, during the observed period, this productivity has generally increased with increasing of the number of WLU, but at a decreasing rate, which has turned into zero after the number of WLU has increased over 45 million per year. Such development has indicated how sustainability of the system has vanished with respect to this indicator during the period of growth.

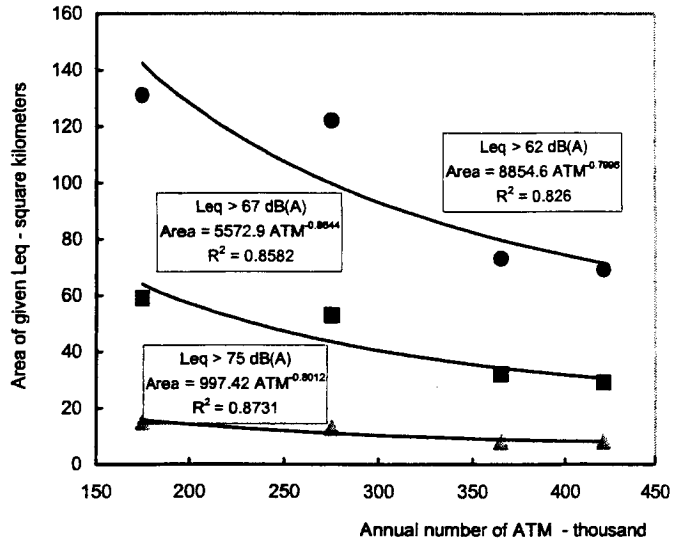
Area of given Leq - square kilometers
Annual number of ATM - thousand
Leq > 62 dB(A)
Area = 8854.6 ATM^0.7995
R² = 0.826
Leq > 67 dB(A)
Area = 5572.9 ATM^0.8544
R² = 0.8582
Leq > 75 dB(A)
Area = 997.42 ATM^0.8012
R² = 0.8731

**Figure 5c** Noise efficiency at Frankfurt Airport – period 1987 – 1999 (Compiled from Fraport, 2001)

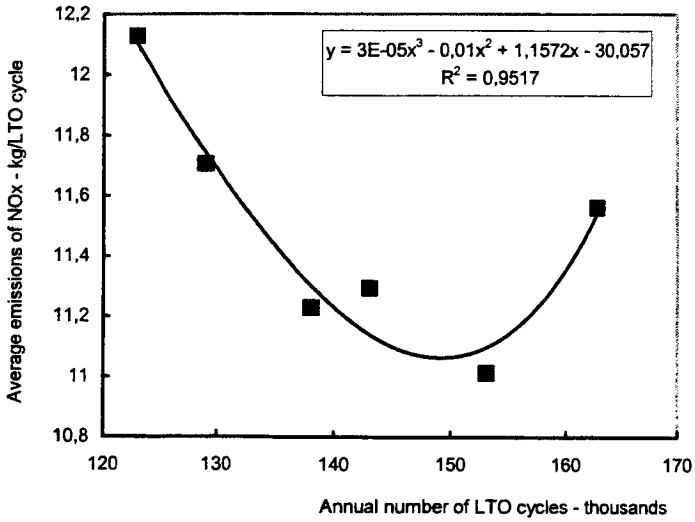


**Figure 5d** Air pollution efficiency at Zurich airport: period 1997-2000: (Compiled from Zurich Airport, 2001)

Figure 5c illustrates noise efficiency at Frankfurt airport (Germany) expressed by the area of land covered by the equivalent constant sound level $L_{eq}$ (= 62, 67 and 75 dB(A)) in dependence on the annual number of ATM (Air Transport Movements). As can be seen, for given number of ATM, for larger $L_{eq}$ this area has been smaller, and vice versa, which has been intuitively expected. As well, the area of land affected by given $L_{eq}$ has decreased with increasing of the number of ATM. Both measures has indicated that the area around the airport exposed to the given level of noise has generally squeezed despite increasing of the traffic volume. This certainly has been achieved by replacing noisier with quieter aircraft and modifications of the operational procedures at and around the airport. Consequently, according to this indicator the airport has been developing in a sustainable way.

Figure 5d illustrates air pollution efficiency of Zurich airport (Switzerland) expressed by the quantity of $N_{ox}$ per LTO cycle in dependence on the number of LTO cycles carried out. As can bee seen, this efficiency has been achieved by decreasing of this emission despite increasing of the number of LTO cycles, primarily through modernization of the aircraft fleet. However, this emission has started to increase when the number of LTO cycles has exceeded 150 thousands, primarily due to more intensive use of the larger aircraft. This has clearly indicated compromising of the already achieved sustainability trend.

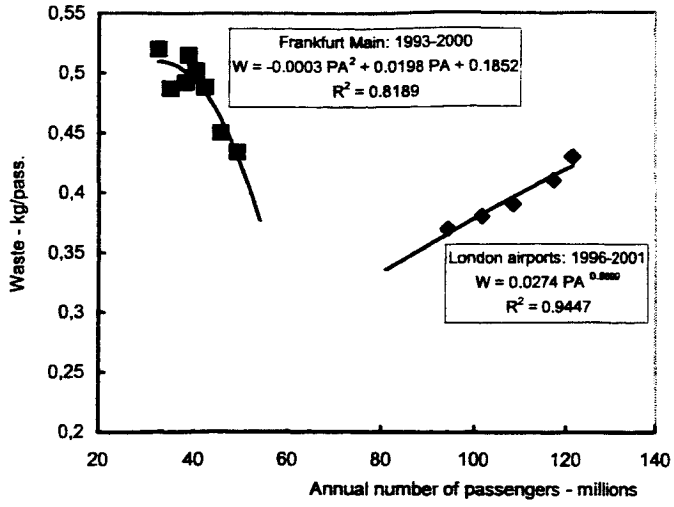
Frankfurt Main: 1993-2000
W = -0.0003 PA² + 0.0198 PA + 0.1852
R² = 0.8189
London airports: 1996-2001
W = 0.0274 PA
R² = 0.9447
Waste - kg/pass.
Annual number of passengers - millions

**Figure 5e** Waste efficiency at European airports (Compiled from Fraport, 2001; BAA, 2001)

Figure 5e illustrates waste efficiency in terms of the quantity of waste per passenger in dependence on the annual number of passengers accommodated at Frankfurt Main (Germany) and three London airports (Heathrow, Stansted, Gatwick) (UK).

As can be seen, this quantity has decreased at Frankfurt Main and increased at London airports with increasing of the annual number of passengers, which has indicated their sustainable and unsustainable development, respectively, with respect to this indicator.

iii) ATC/ATM

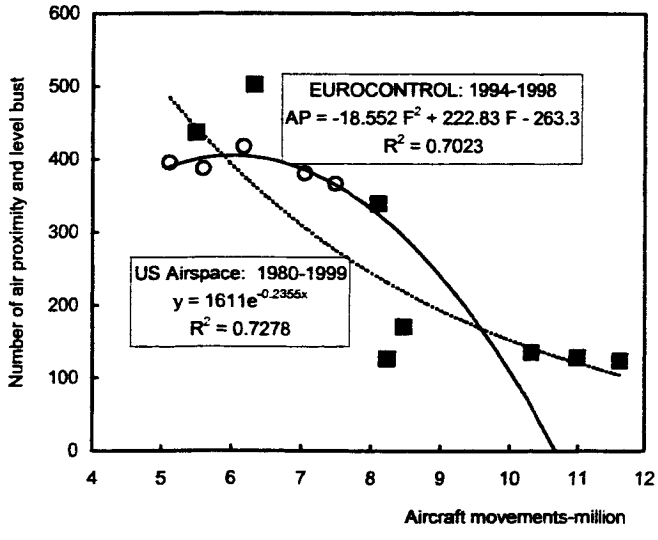
EUROCONTROL: 1994-1998
AP = -18.552 F² + 222.83 F - 263.3
R² = 0.7023
US Airspace: 1980-1999
y = 1611e^-0.2355x
R² = 0.7278
Number of air proximity and level bust
Aircraft movements-million

**Figure 6** Safety in European and U.S. airspace (Compiled from EC, 1999a; DETR, 2000; BTS, 2001)

Figure 6 illustrates safety of the air traffic control system in terms of the number of air proximities and level busts dependent on the annual number of aircraft movements in the airspace of Europe and U.S. As can be seen, in both regions, this indicator has generally decreased with increasing of the number of aircraft movements, but the rates of decrease have been different. Nevertheless, both systems have been developed in a sustainable way according to this indicator, i.e., flying has been less and less with a risk of air proximities with increasing of traffic density.

iv) Airlines

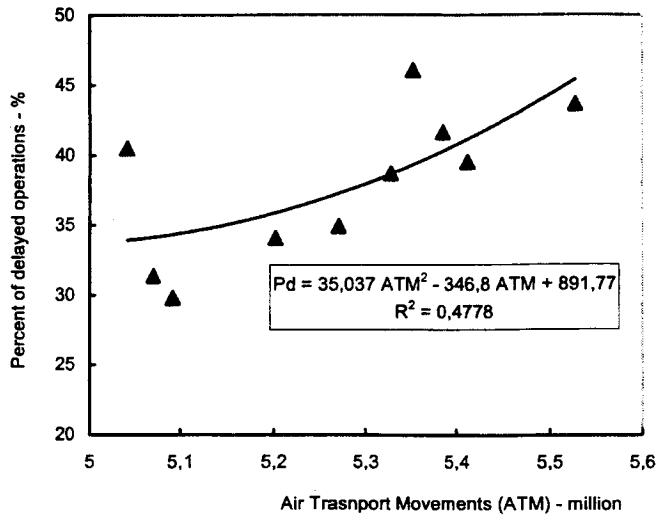


**Figure 7a** Punctuality of Major ten U.S. air carriers: period 1988 – 1999 (Compiled from USDT, 2001)

Figure 7a illustrates punctuality of the ten major U.S. airlines. It has been expressed as the proportion of the delayed ATM (Air Transport Movements) in dependence on the total number of ATM carried out per year during the period 1988-1999. As can be seen, generally, the proportion of cancelled flights has generally increased at an increased rate with increasing of the number of the number of ATM, which has implied lack of the system sustainable development with respect to this indicator.

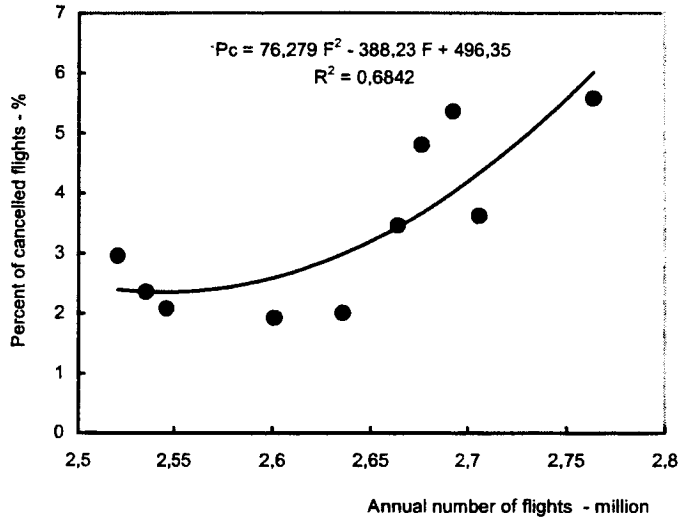


**Figure 7b** Reliability of Major ten U.S. air carriers: period 1988–1999 (Compiled from USDT, 2001)

Figure 7b illustrates reliability of the ten U.S. major airlines in terms of the proportion of cancelled flights dependent on the total number of flights carried out per year. All reasons for cancellations, from bad weather to technical failures, have been included. As can be seen, similarly as punctuality, this proportion has increased at an increasing rate with increasing of the totals number of flights. Such relationship has implied a lack of sustainability of the system development with respect to this indicator.

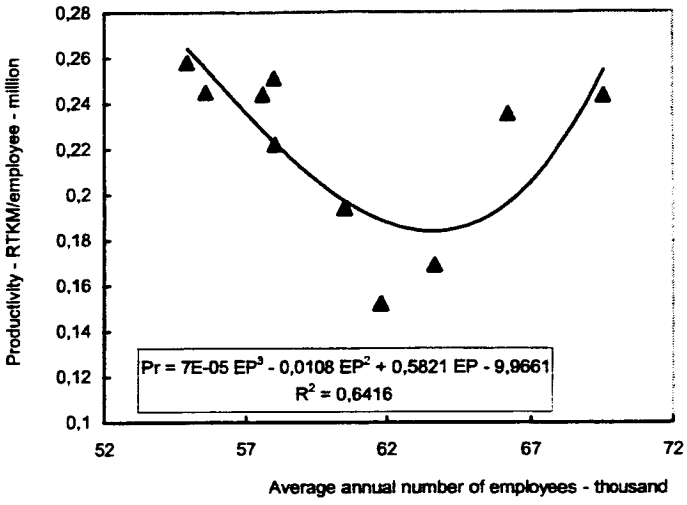


**Figure 7c** Labour productivity of Lufthansa group: period 1991-2000 (Compiled from Lufthansa, 2000)

Figure 7c illustrates productivity at Lufthansa Group (Germany) expressed as RTK per employee in dependence on the average annual number of employees. As can be seen, productivity has decreased until the number of employees has reached about 63 thousands but after that it has increased despite the number of employees has continued to rise. On the one hand this has happened due to the airline improvements. On the other, the strong force has been intensification of the long-haul intercontinental flights. Consequently, according to this indicator the group has changed its long-term trend of development from unsustainable to sustainable.

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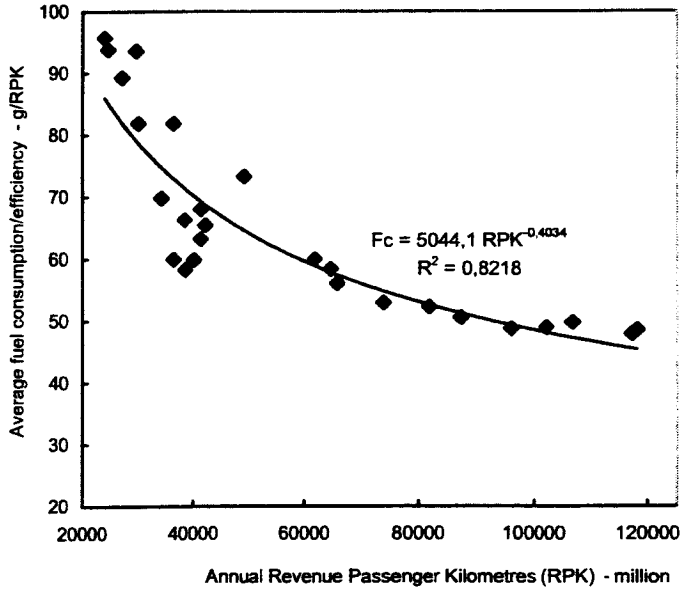


**Figure 7d** Fuel efficiency at British Airways: period 1974-2000 (Compiled from BA, 2001)

Figure 7d illustrates efficiency of fuel consumption at British Airways during the period 1974-2000. It has been expressed in terms of grams of fuel consumed per RPK (Revenue Passenger Kilometer) in dependence on the total annual volume of RPK. As can be seen, this consumption has generally decreased at a decreasing rate with increasing of the volume of RTK, which has also meant decreasing of the associated air pollution. Such undoubtedly long-term sustainable development has been achieved because the airline has permanently modernized its fleet on the one hand and been provided with more effective services by ATM/ATC during operations over its air route network on the other.

v) Airspace manufacturers

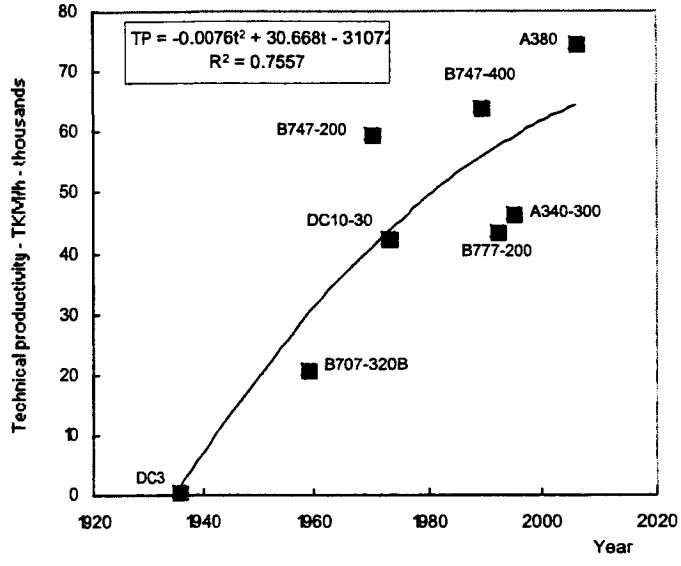


**Figure 8a** Aircraft technical productivity (Compiled from FI, 2000, 2001)

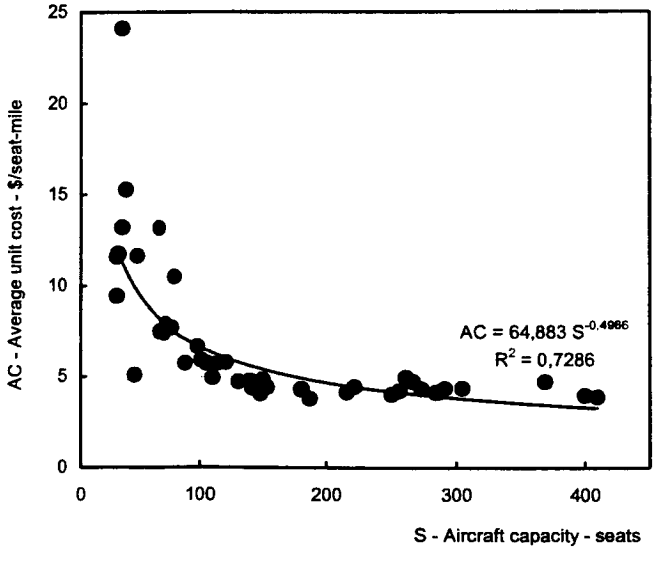


**Figure 8b** Aircraft eefficiency (Compiled from FAA, 1998)

Figure 8a illustrates the main steps in progress in development of the aircraft technical productivity in terms of the number of TKM/h (Ton Kilometers per Hour). As can be seen, this productivity has been increasing over time thanks to both airlines and their requirements as well as to capabilities of aerospace manufacturers. After DC 3, the rise of technical productivity has been primarily achieved by developing the larger aircraft and much less by increasing of the aircraft operating (cruising) speed. A culmination of development of this productivity will certainly be reached after introducing A380. The development of aircraft capacity has simultaneously included development and upgrading of engines (jet engines after DC3) in terms of their fuel and air pollution efficiency on the one hand and sophisticated avionics on the other. Consequently, the system has recorded the long-term sustainable development.

Figure 8b illustrates development of aircraft efficiency in terms of the average cost per seat mile dependent on the aircraft capacity (the number of seats). As can be seen, this cost has decreased at a decreasing rate with increasing of the aircraft size thus indicating the larger aircraft as being more efficient in relative terms. If development of bigger aircraft has been an objective in terms of sustainability, then such development has been sustainable in the long term.

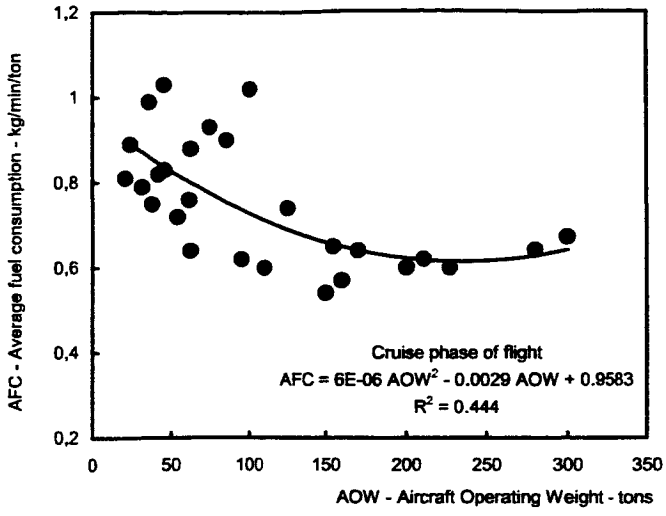


**Figure 8c** Fuel efficiency (Compiled from EUROCONTROL, 1998)

Figure 8c illustrates the aircraft fuel efficiency in terms of the average fuel consumption per unit of time and per unit of weight dependent on the aircraft operating weight. As can be seen, this consumption has decreased at a decreasing rate with increasing of the aircraft weight, which has implied higher relative fuel efficiency of the larger aircraft up to the weight of about 250 tons. For heavier aircraft, this advantage has disappeared and they have even shown to be less fuel-efficient. Consequently using larger aircraft up to a certain size has seemed to be more sustainable with respect to this indicator then otherwise.

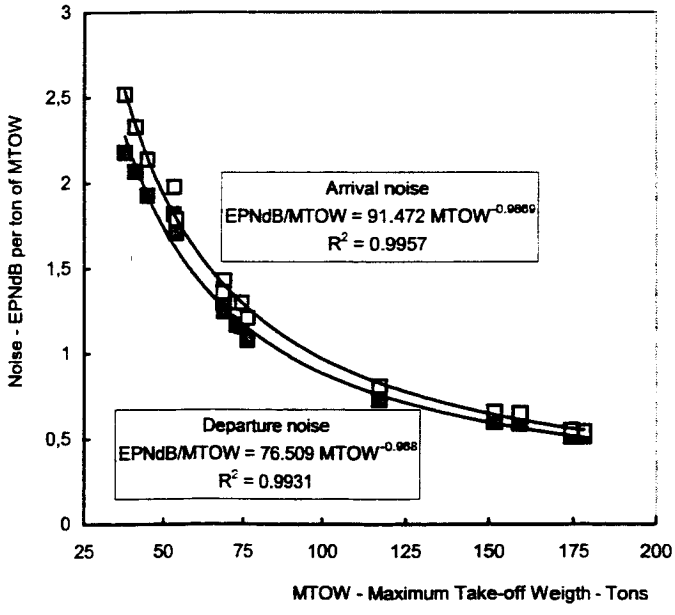


**Figure 8d** Noise efficiency (Compiled from HA, 1999; FI, 2000; 2001)

Figure 8d illustrates the aircraft noise efficiency expressed as the level of noise in terms of EPNdB (Equivalent Persistent Noise in Decibels) per unit of the aircraft maximum take-off weight in dependence of this weight. As can be seen, the relative level of noise has decreased more than proportionally with increasing of the aircraft maximum take-off weight for both aircraft arrivals and departures. The arrival noise has been slightly higher than the departure noise. Again, if development of bigger and relatively quieter aircraft has been an objective, the progress has been sustainable with respect to this indicator.

vi) Community members

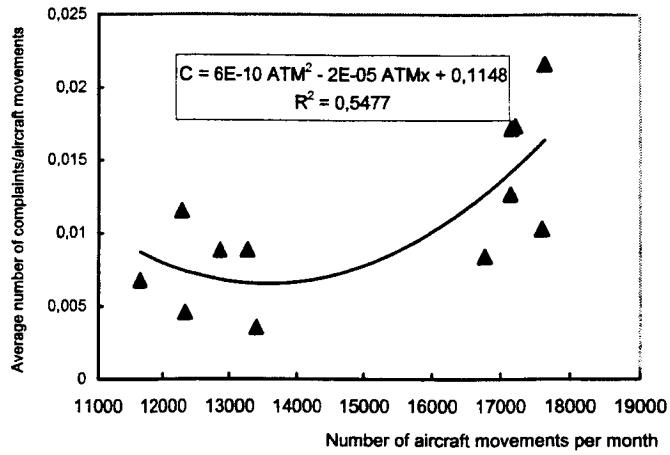


**Figure 9** Noise disturbance (Compiled from MA, 1999)

Figure 9 illustrates noise disturbance at Manchester Airport (UK). This is expressed by the average number of complaints per ATM (Air Transport movement) in dependence on the total number of ATM carried out during given period of time. As can be seen, up to about 13 thousand movements carried out per month, the average number of complaints has decreased but after that it has been increasing more than proportionally. This has indicated that the airport has grown in an unsustainable way according to the attitudes of local population.

vii) Governments

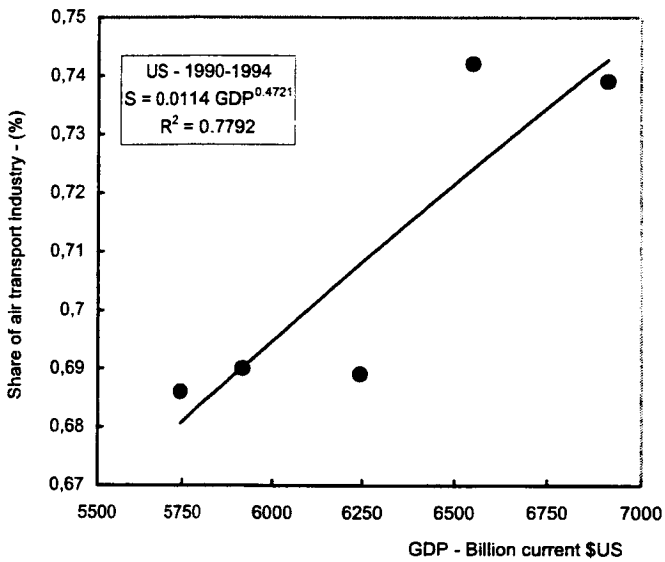


**Figure 10a** Economic welfare: U.S. air transport system: period 1990-1994 (Compiled from Han X., Fang, B., 1998)

Figure 10a illustrates economic welfare obtained by the U.S air transport industry expressed by its share in the total GDP (Gross Domestic Product) during the limited period 1990-1994. As can be seen, this share has increased linearly with increasing of the national GDP, which has indicated the industry's ability to permanently upgrade its contributions to the national economy (from 0.68% in 1990 to 0.74% in 1994 in the total GDP).

Consequently, the industry has developed in a sustainable way during the observed period with respect to this indicator.

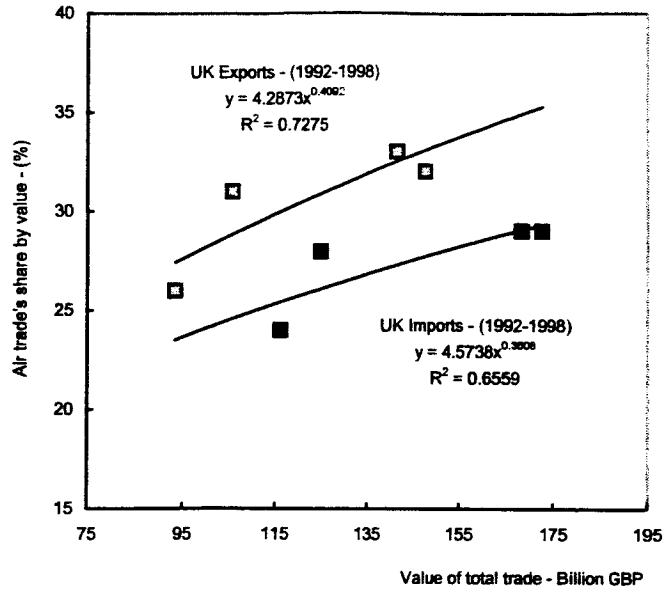


**Figure 10b** Internalisation & globalization of UK Trade: Period 1992-1998 (Compiled from DETR, 2000c)

Figure 10b illustrates an example of contribution of the national air transport system to globalization and internalization of the UK trade sector during the period 1992-1998. As can be seen, in the country's import and export, the share of air transport by value has been rising with increasing of the total value of trade. This has indicated the system ability to gain more expensive shipments, which in turn has meant its sustainable development with respect to this indicator.

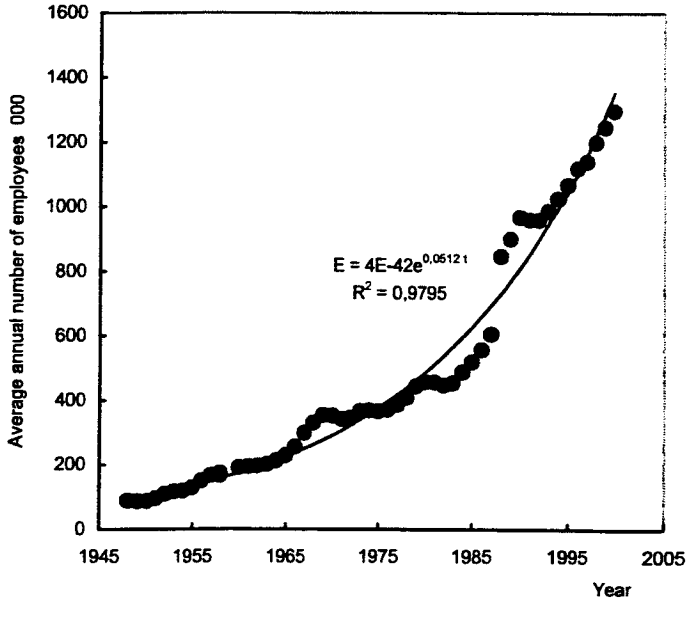


**Figure 10c** Overall employment at U.S. air transport industry (Compiled from BEA, 2001)

Figure 10c illustrates development of employment in the U.S. air transport industry during the period 1945-2001. As can be seen, the long-term growth of the number of employees has been approximately exponential. It has started approximately from one hundred thousands in the year 1945 and reached about one million and four hundred thousands in the year 2001, which has been fourteen-times increase. There have been the variations around the general trend indicating restructuring of the sector after deregulation of the airline industry in the year 1978 and global crisis before and after the Gulf war in 1991. Nevertheless, in the long term, according to this indicator, the system has been developing in the sustainable way.

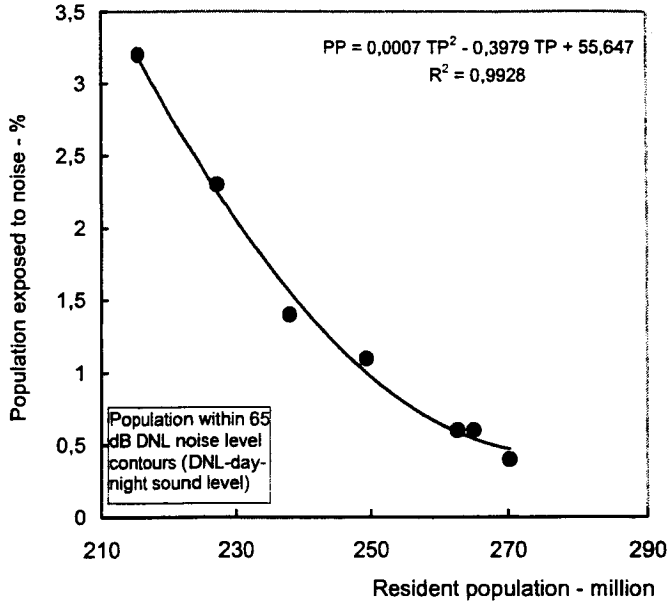


**Figure 10d** Global noise efficiency around 250 largest U.S. airports: period 1975-1998 (Compiled from BTS, 2001)

Figure 10d illustrates global noise efficiency at 250 U.S. main airports. This efficiency has been expressed as the proportion of population exposed to the air transport noise in dependence on the total resident population. As can be seen, during the period 1975-1998, this proportion has been decreasing more than proportionally with increasing of population, from 3% to less than a half percent. Certainly, such long-term trend has been achieved by improvements of airport and land use planning resettlement of population previously lived close to these airports, improvements of aircraft operational procedures and modernization of aircraft fleet. Consequently, according to this indicator the system has been developing in a sustainable way.

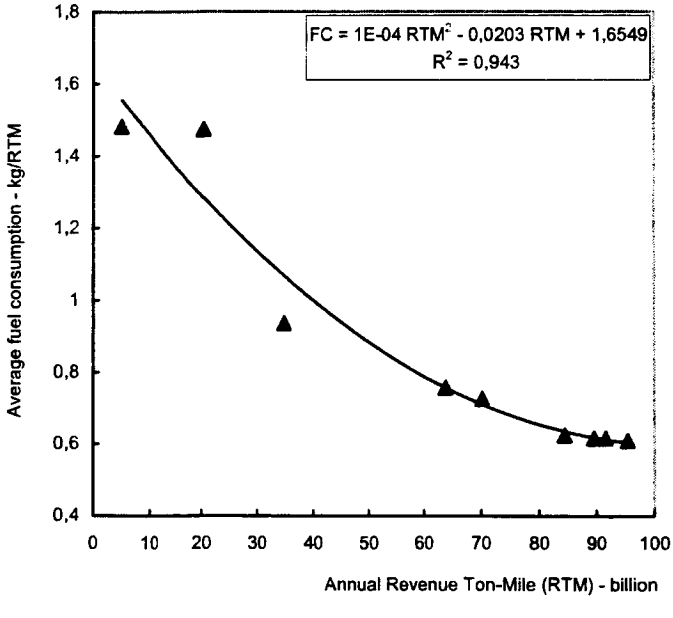


**Figure 10e** Global energy efficiency of the U.S. airline industry: period 1960-1999 (Compiled from BTS, 2001)

Figure 10e illustrates global energy efficiency of the U.S. airline industry expressed by the average fuel consumption per RTM (Revenue Ton Mile) in dependence on the total annual amount of RTM. As can bee seen, this consumption has decreased more than proportionally with increasing of the total amount of RTM, from about 1.6 kg/RTM to just about 0.6 kg/RTM (~2.7 times). At the same time the annual amount of RTM has increased for about five times. The main influencing factors have been improvements in the aircraft design and fleet use. Consequently, with respect to this indicator, the system has developed in a sustainable way during the observed period.

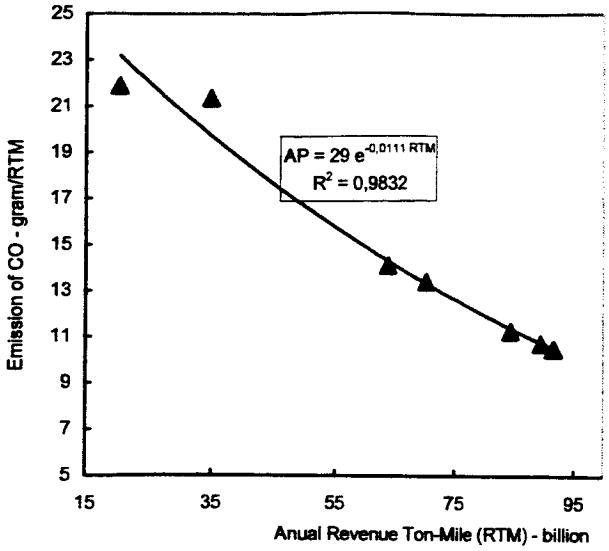


**Figure 10f** Global air pollution efficiency of the U.S. airline industry: period 1970-1998 (Compiled from BTS, 2001)

Figure 10f illustrates global air pollution efficiency of the U.S. airline industry. Similarly as at the fuel consumption case, this efficiency has been expressed by the quantity of CO emitted per RTM (Revenue Ton Mile) in dependence on the annual amount of RTM carried out during the period 1970-1998. As can be seen, more than proportional decrease of this emission, from about 22g/RTM to about 10 g/RTM, with increasing of RTM, from about 16 to about 95 billion RTM per annum, has taken place. The reasons have been the same as in case of fuel consumption including also improvements of aircraft engines in terms of the 'quality of burning' fuel. Consequently, according to this indicator, the system has been developing in a sustainable way.

## 5 CONCLUSIONS

The paper has explained the methodology for assessment of the sustainability of air transport system and its potential application. The methodology has consisted of the indicator systems consisted of the individual indicators and their measures. They have represented the system operational, economic, social and environmental performance. The particular indicators and their measures have been defined in terms of the system positive effects and negative impacts and in dependence on the system output, in both monetary and non-monetary terms. Their relevance for different actors such as users (air travellers), air transport operators, aerospace manufacturers, local communities, governmental authorities at different scales (local, national, international), international air transport associations, pressure groups and public have been also included. In total, fifty-eight individual indicators and their sixty-eight measures have been defined.

The application of the methodology has included estimation of twenty-six indicators. Due to the structure of the particular indicators and availability of the relevant data, almost all cases have related to the U.S. air transport industry while just a few ones have related to the European air transport industry. The results have shown (and confirmed) that the long-term development of the system and its particular components has been sustainable with respect to the most indicators of the economic, social and environmental dimension of performance from the aspects of the most actors involved. Nevertheless, there have been still some doubts about unsustainable indicators of the operational dimension of performance such as

punctuality and reliability of service at airports and airlines, indicators of the environmental dimension of performance such as air pollution, waste efficiency and noise disturbance at airports, and indicators of the economic dimension of performance such as labour productivity of airlines.
Generally, based on the analysed cases, it can be said that the air transport system, with few exceptions, has shown sustainable development under given circumstances and during observed period. Stable sustainable trends have been established. However, after September 11 terrorists' attack on the U.S. (2001), the operational and economic dimension of performance have become of the growing importance illustrating the system and its components' struggle for survival. The questions about the system future sustainable development as well as comparison of its with the sustainability of other transport modes as well as other sectors of the national and international economy by using the same or modified methodology are waiting for reply.

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# Regulation, Competition and Network Evolution in Aviation

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ABSTRACT

Our focus is the evolution of business strategies and network structure decisions in the commercial passenger aviation industry. The paper reviews the growth of hub-and-spoke networks as the dominant business model following deregulation in the latter part of the 20th century, followed by the emergence of value-based airlines as a global phenomenon at the end of the century. The paper highlights the link between airline business strategies and network structures, and examines the resulting competition between divergent network structure business models. In this context we discuss issues of market structure stability and the role played by competition policy.

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## *1. Introduction*

Taking a snapshot of the North American commercial passenger aviation industry in the spring of 2003, the signals on firm survivability and industry equilibrium are mixed; some firms are under severe stress while others are succeeding in spite of the current environment.[1] In the US, we find United Airlines in Chapter 11 and US Airways emerging from Chapter 11 bankruptcy protection. We find American Airlines having just reported the largest financial loss in US airline history, while Delta and Northwest Airlines along with smaller carriers like Alaska, America West and several regional carriers are restructuring and employing cost reduction strategies. We also find Continental Airlines surviving after having been in and out of Chapter 11 in recent years, while Southwest Airlines continues to be profitable. In Canada, we find Air Canada in CCAA bankruptcy protection (the Canadian version of chapter 11), after reporting losses of over $500 million for the year 2002 and in March 2003.[2] Meanwhile WestJet, like Southwest continues to show profitability, while two new carriers, Jetsgo and CanJet (reborn), have entered the market.

Looking at Europe, the picture is much the same, with large full-service airlines (FSAs hereafter) such as British Airways and Lufthansa sustaining losses and suffering financial difficulties, while value-based airlines (VBA's) like Ryanair and EasyJet continue to grow and prosper. Until recently, Asian air travel markets were performing somewhat better than in North America, however the current SARS epidemic is having a severe negative effect on many Asian airlines.[3]

Clearly, the current environment is linked to several independent negative demand shocks that have hit the industry hard.[4] A broad multi-country macroeconomic slowdown was already underway in 2001,

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[1] This scenario is true in most other countries as well; Australia, new Zealand and the EU.

[2] CCAA refers to the Companies Creditors Arrangement Act.

[3] SARS (Severe Acute Respiratory Syndrome) began n China and quickly spread to Hong Kong, Vietnam, Singapore, Canada and is emerging in the US and EU. Cathay Pacific, based in Hong Kong has seen passenger traffic drop from 35,000 per day to less than 10,000.

[4] People want to get from A to B for business, family and vacation purposes. The demand will therefore depend upon the overall health of the economy but it will also depend on the competitive environment for air services. The growth in air travel over the last few decades was not simply a matter of general economic growth but also due to changes in the rules governing trade, such as under the WTO (World Trade Organization) and the liberalization of markets, both domestic and internationally which led to falling airfares and broader service. The demand for air travel has also grown due to shifts in the structure of economies from manufacturing to service economies and service industries are more aviation intensive than manufacturing. Developed economies as in Europe and North America as well as Australia and New Zealand, have an increasing proportion of GDP provided by service industries particularly tourism. One sector that is highly aviation intensive

prior to the 9-11 tragedy, which gave rise to the 'war on terrorism' followed by the recent military action in Iraq. Finally, the SARS virus has not only severely diminished the demand for travel to areas where SARS has broken out and led to fatalities, but it has also helped to create yet another reason for travelers to avoid visiting airports or traveling on aircraft, based on a perceived risk of infection. All of these factors have created an environment where limited demand and price competition has favoured the survival of airlines with a low-cost, low price focus.

In this paper we examine the evolution of air transport networks after economic deregulation, and the connection between networks and business strategies, in an environment where regulatory changes continue to change the rules of the game. This introductory section continues with a descriptive account and analysis of developments in the aviation sector since deregulation in the US. Section 2 describes and contrasts distinguishing elements of the two dominant but divergent business models: the traditional FSA business model, which is tied to the use of hub-and-spoke networks and the VBA business model, which utilizes a point-to-point network structure. In section 3 we review and develop some insights from the economics of networks applied to airline competition and in section 4, we discuss two issues relating to competition and regulation in commercial passenger aviation: stability in market structure and the application of competition policy. Some concluding remarks are offered in section 5.

### *1.1 The story so far...*

The deregulation of the US domestic airline industry in 1978 was the precursor of similar moves by most other developed economies in Europe (beginning 1992-1997), Canada (beginning in 1984), Australia (1990) and New Zealand (1986).[5] The argument was that the industry was mature and

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is the high technology sector. It is footloose and therefore can locate just about anywhere; the primary input is human capital. It can locate assembly in low cost countries and this was enhanced under new trade liberalization with the WTO.

[5] Canada's deregulation was not formalised under the National Transportation Act until 1987. Australia and New Zealand signed an open skies agreement in 2000, which created a single Australia-New Zealand air market, including the right of cabotage. Canada and the US signed an open skies agreement well in 1996 but not nearly so liberal as the Australian-New Zealand one.

capable of surviving under open market conditions subject to the forces of competition rather than under economic regulation.[6]

Prior to deregulation in the US, some airlines had already organized themselves into hub-and-spoke networks. Delta Airlines, for example, had organized its network into a hub at Atlanta with multiple spokes. Other carriers had evolved more linear networks with generally full connectivity and were reluctant to shift to hub-and-spoke for two reasons. First, regulations required permission to exit markets and such exit requests would likely lead to another carrier entering to serve 'public need'. Secondly, under regulation it was not easy to achieve the demand side benefits associated with networks because of regulatory barriers to entry. In the era of economic regulation the choice of frequency and ancillary service competition were a direct result of being constrained in fare and market entry competition. With deregulation, airlines gained the freedom to adapt their strategies to meet market demand and to reorganize themselves spatially. Consequently, hub-and-spoke became the dominant choice of network structure.

The hub-and-spoke network structure was perceived to add value on both the demand and cost side. On the demand side, passengers gained access to broad geographic and service coverage, with the potential for frequent flights to a large number of destinations.[7] Large carriers provided lower search and transactions costs for passengers and reduced through lower time costs of connections. They also created travel products with high convenience and service levels – reduced likelihood of lost luggage, in-flight meals and bar service for example. The FSA business model thus favoured high service levels which helped to build the market the market at a time when air travel was an unusual or infrequent activity for many individuals. Building the market not only meant encouraging more air travel but also expanding the size of the network which increased connectivity and improved aircraft utilization.

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[6] In contrast to deregulation within domestic borders, international aviation has been slower to introduce unilateral liberalization. Consequently the degree of regulation varies across routes, fares, capacity, entry points (airports) and other aspects of airline operations depending upon the countries involved.. The US-UK, German, Netherlands and Korea bilaterals are quite liberal, for example. In some cases, however, most notably in Australasia and Europe, there have been regional air trade pacts, which have deregulated markets between and within countries. The open skies agreement between Canada and the US is similar to these regional agreements.

[7] Like telephone networks, adding a point to a hub and spoke system creates 2n connections.

On the cost side the industry was shown to have few if any economies of scale, but there were significant economies of density. Feeding spokes from smaller centres into a hub airport enabled full service carriers to operate large aircraft between major centres with passenger volumes that lowered costs per available seat.

An early exception to the hub-and-spoke network model was Southwest Airlines. In the US, Southwest Airlines was the original 'value-based airline' (VBA) representing a strategy designed to build the market for consumers whose main loyalty is to low price travel. This proved to be a sustainable business model and Southwest's success was to create a blueprint for the creation of other VBA's around the world. The evolution has also been assisted by the disappearance of charter airlines with deregulation as FSA's served a larger scope of the demand function through their yield management system.

Meanwhile, benefits of operating a large hub-and-spoke network in a growing market led to merger waves in the US (mid-1980s) and in Canada (late-1980s) and consolidation in other countries of the world. Large firms had advantages from the demand side, since they were favoured by many passengers and most importantly by high yield business passengers. They also had advantages from the supply side due to economies of density and economies of stage length.[8] In most countries other than the US there tended to be high industry concentration with one or at most two major carriers. It was also true that in most every country except the US there was a national (or most favoured) carrier that was privatized at the time of deregulation or soon thereafter.

In Canada in 1995 the Open Skies agreement with the US was brought in.[9] Around this time we a new generation of VBA's emerged. In Europe, Ryanair and EasyJet experienced rapid and dramatic growth following deregulation within the EU. Some FSA's responded by creating their own VBAs: British Airways created GO, KLM created BUZZ and British Midland created BMiBaby for example. WestJet airlines started service in western Canada in 1996 serving three destinations and has grown continuously since that time.

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[8] Unit costs decrease as stage length increases but at a diminishing rate.
[9] There was a phase in period for select airport sin Canada as well as different initial rules for US and Canadian carriers.

Canadian Airlines, faced with increased competition in the west from WestJet as well as aggressive competition from Air Canada on longer haul routes, was in a severe financial by the late 1990s. A bidding war for a merged Air Canada and Canadian was initiated and in 2000, Air Canada emerged the winner with a 'winners curse', having assumed substantial debt and constraining service and labour agreements. Canada now had one FSA and three or four smaller airlines, two of which were VBAs.

In the new millennium, some consolidation has begun to occur amongst VBA's in Europe with the merger of, EasyJet and GO in 2002, and the acquisition of BUZZ by Ryanair in 2003. More importantly perhaps, the VBA model has emerged as a global phenomenon with VBA carriers such as Virgin Blue in Australia, GOL in Brazil, Germania and Hapag-Lloyd in Germany and Air Asia in Malaysia.

Looking at aviation markets since the turn of the century, casual observation would suggest that a combination of market circumstances created an opportunity for the propagation of the VBA business model – with a proven blueprint provided by Southwest Airlines. However a question remains as to whether something else more fundamental has been going on in the industry to cause the large airlines and potentially larger alliances to falter and fade. If the causal impetus of the current crisis was limited to cyclical macro factors combined with independent demand shocks, then one would expect the institutions that were previously dominant to re-emerge once demand rebounds. If this seems unlikely it is because the underlying market environment has evolved into a new market structure, one in which old business models and practices are no longer viable or desirable. The evolution of business strategies and markets, like biological evolution is subject to the forces of selection. Airlines who cannot or do not adapt their business model to long-lasting changes in the environment will disappear, to be replaced by those companies whose strategies better fit the evolved market structure. But to understand the emerging strategic interactions and outcomes of airlines one must appreciate that in this industry, business strategies are necessarily tied to network choices.

## 2. Network structure and business strategy

The organization of production spatially in air transportation networks confers both demand and supply side network economies and the choice of network structure by a carrier necessarily reflects aspects of its business model and will exhibit different revenue and cost drivers. In this section we outline important characteristics of the business strategy and network structures of two competing business models: the full service strategy (utilizing a hub-and-spoke network) and the low cost strategy model which operates under a partial point-to-point network structure.

### *2.1 Hub-and-spoke networks and the full-service strategy*

The full service business model is predicated on broad service in product and in geography bringing customers to an array of destinations with flexibility and available capacity to accommodate different routings, no-shows and flight changes. The broad array of destinations and multiple spokes requires a variety of aircraft with differing capacities and performance characteristics. The variety increases capital, labour and operating costs. This business model labours under cost penalties and lower productivity of hub-and-spoke operations including long aircraft turns, connection slack, congestion, and personnel and baggage online connections. These features take time, resources and labour, all of which are expensive and are not easily avoided. The hub-and-spoke system is also conditional on airport and airway infrastructure, information provision through computer reservation and highly sophisticated yield management systems.

The network effects that favoured hub and spoke over linear connected networks lie in the compatibility of flights and the internalization of pricing externalities between links in the network. A carrier offering flights from city A to city B through city H (a hub) is able to collect traffic from many origins and place them on a large aircraft flying from H to B, thereby achieving density economies. In contrast A carrier flying directly from A to B can achieve some direct density economies but more importantly gains aircraft utilization economies. In the period following deregulation, density economies were larger than aircraft utilization economies on many routes, owing to the limited size of many origin and destination markets.

On the demand side, FSA's could maximize the revenue of the entire network by internalizing the externalities created by complementarities between links in the network. In our simple example, of a

flight from A to C via hub H the carrier has to consider how pricing of the AH link might affect the demand for service on the HB link. If the service were offered by separate companies, the company serving AH will take no consideration of how the fare it charged would influence the demand on the HB link since it has no right to the revenue on that link. The FSA business model thus creates complexity as the network grows, making the system work effectively requires additional features most notably, yield management and product distribution. In the period following deregulation, technological progress provided the means to manage this complexity, with large information systems and in particular computer reservation systems. Computer reservation systems make possible sophisticated flight revenue management, the development of loyalty programs, effective product distribution, revenue accounting and load dispatch. They also drive aircraft capacity, frequency and scheduling decisions. As a consequence, the FSA business model places relative importance on managing complex schedules and pricing systems with a focus on profitability of the network as a whole rather than individual links.

The FSA business model favours a high level of service and the creation of a large service bundle (in-flight entertainment, meals, drinks, large numbers of ticketing counters at the hub etc.) which serves to maximize the revenue yields from business and long-haul travel. An important part of the business service bundle is the convenience that is created through fully flexible tickets and high flight frequencies. High frequencies can be developed on spoke routes using smaller feed aircraft, and the use of a hub with feed traffic from spokes allows more flights for a given traffic density and cost level. More flights reduce total trip time, with increased flexibility. Thus, the hub-and-spoke system leads to the development of feed arrangements along spokes. Indeed these domestic feeds contributed to the development of international alliances in which one airline would feed another utilizing the capacity of both to increase service and pricing.

### *2.2 Point-to-point networks and the low-cost strategy*

Like the FSA model, the VBA business plan creates a network structure that can promote connectivity but in contrast trades off lower levels of service, measured both in capacity and frequency, against lower fares. In all cases the structure of the network is a key factor in the success of VBAs even in the

current economic and demand downturn. VBAs tend to exhibit common product and process design characteristics that enable them to operate at a much lower cost per unit of output.[10]

On the demand side, VBAs have created a unique value proposition through product and process design that enables them to eliminate, or "unbundle" certain service features in exchange for a lower fare. These service feature trade-offs are typically: less frequency, no meals, no free, or any, alcoholic beverages, more passengers per flight attendant, no lounge, no interlining or code-sharing, electronic tickets, no pre-assigned seating, and less leg room. Most importantly the VBA does not attempt to connect its network although their may be connecting nodes. It also has people use their own time to access or feed the airport.[11]

There are several key areas in process design (the way in which the product is delivered to the consumer) for a VBA that result in significant savings over a full service carrier. One of the primary forms of process design savings is in the planning of point-to-point city pair flights, focusing on the local origin and destination market rather than developing hub systems. In practice, this means that flights are scheduled without connections and stops in other cities. This could also be considered product design, as the passenger notices the benefit of traveling directly to their desired destination rather than through a hub. Rather than having a bank of flights arrive at airports at the same time, low-cost carriers spread out the staffing, ground handling, maintenance, food services, bridge and gate requirements at each airport to achieve savings.

Another less obvious, but important cost saving can be found in the organization design and culture of the company. It is worth noting at this point that the innovator of product, process, and organizational re-design is generally accepted to be Southwest Airlines. Many low-cost start-ups have attempted to replicate that model as closely as possible; however, the hardest area to replicate has proved to be the organization design and culture.[12]

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[10] Product design refers to the "look and feel" of a product, and is the most visible difference between low-cost and full service carriers to the airline passenger.
[11] Southwest Airlines claims passengers will travel up to 1-2 hours to access an airport with lower fares. In Canada, Westjet has observed the same phenomena.

Extending the "look and feel" to the aircraft, there is a noticeable strategy for low-cost airlines. Successful VBAs focus on a homogeneous fleet type (mostly the Boeing 737 but this is changing; e.g. Jet Blue with A320 fleet). The advantages of a 'common fleet' are numerous. Purchasing power is one - with the obvious exception of the aircraft itself, heavy maintenance, parts, supplies; even safety cards are purchased in one model for the entire fleet. Training costs are reduced- with only one type of fleet, not only do employees focus on one aircraft and become specialists, but economies of density can be achieved in training.

The choice of airports is typically another source of savings. Low-cost carriers tend to focus on secondary airports that have excess capacity and are willing to forego some airside revenues in exchange for non-airside revenues that are developed as a result of the traffic stimulated from low cost airlines. In simpler terms, secondary airports charge less for landing and terminal fees and make up the difference with commercial activity created by the additional passengers. Further, secondary airports are less congested, allowing for faster turn times and more efficient use of staff and the aircraft. The average taxi times shown in table 1 (below) are evidence of this with respect to Southwest in the US and one only has to consider the significant taxi times at Pearson Airport in Toronto to see why Hamilton is such an advantage for WestJet.

Essentially, VBAs have attempted to reduce the complexity and resulting cost of the product by unbundling those services that are not absolutely necessary. This unbundling extends to airport facilities as well, as VBAs struggle to avoid the costs of expensive primary airport facilities that were designed with full service carriers in mind. While the savings in product design are the most obvious to the passenger, it is the process changes that have produced greater savings for the airline.

The design of low-cost carriers facilitates some revenue advantages in addition to the many cost advantages, but it is the cost advantages that far outweigh any revenue benefits achieved. These revenue advantages included simplified fare structures with 3-4 fare levels, a simple 'yield' management system, and the ability to have one-way tickets. The simple fare structure also facilitates Internet booking. However, what is clearly evident is the choice of network is not independent of the

[12] It should also be noted that the VBA model is not generic. Different low cost carriers do different things and like all

firm strategy. The linear point-to-point network of VBAs allows it to achieve both cost and revenue advantages.

Table 1 below, compares key elements of operations for US airlines 737 fleets. One can readily see a dramatic cost advantage for Southwest Airlines compared to FSAs. In particular, Southwest is a market leader in aircraft utilization and average taxi times.

**Table 1**

**Aircraft Utilization and Operating Cost of 737-300 and 737-700 fleets (3rd Q, 2001)**

| Airline | Departures | Block Hours | Flight Hours | Average Stage Length(miles) | Average Taxi Time in Minutes[13] | Cost per Available Seat Mile (US cents) |
|---|---|---|---|---|---|---|
| Frontier | 4.5 | 11.2 | 9.8 | 933 | 19 | 5.6 |
| Southwest | 7.6 | 10.5 | 8.9 | 472 | 13 | 4.0 |
| ATA | 3.9 | 10.4 | 8.8 | 1,032 | 25 | 4.3 |
| United | 5.0 | 9.3 | 7.5 | 639 | 22 | 8.1 |
| Continental | 3.4 | 8.6 | 7.1 | 895 | 26 | 6.2 |
| America West | 4.5 | 8.3 | 6.7 | 602 | 21 | 6.2 |
| US Airways | 5.1 | 8.3 | 6.3 | 466 | 24 | 8.9 |
| Delta | 4.6 | 7.8 | 6.1 | 546 | 22 | 7.1 |

Source: Aviation Daily, March 27, 2002.

If one looks at the differences in the US between VBAs like Southwest and FSAs, there is a 2:1 cost difference. This difference is similar to what is found in Canada between WestJet and Air Canada as well as in Europe. These carriers buy the fuel and capital in the same market, and although there may be some difference between carriers due to hedging for example, these are not structural or permanent changes. The vast majority of the cost difference relates to product and process complexity. This complexity is directly tied to the design of their network structure.

Table 2 compares cost drivers for FSAs and VBAs in Europe. The table shows the key underlying cost drivers and where a VBA like Ryanair has an advantage over FSAs in crew and cabin personnel costs, airport charges and distribution costs. The first two are directly linked to network design. A hub-and-

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businesses we see continual redefinition of the model.

[13] Calculated using the difference between block times, flight times and dividing by the number of departures.

spoke network is service intensive and high cost. Even distribution cost-savings are related indirectly to network design because VBAs have simple products and use passengers' time as an input to reduce airline connect costs.

**Table 2**
**Comparison of Cost Drivers for VBAS and FSAs**

Unit Costs in US$ ASK adjusted for 800 km Stagelength (2001)

| | 3Major EU Flag Carriers | Ryanair | easyjet |
|---|---|---|---|
| Aircraft Ownership | 1.2 | 0.7 | 1.0 |
| Airport/ATC | 3.8 | 1.2 | 1.0 |
| Distribution | 1.9 | 0.5 | 0.2 |
| Crew | 1.4 | 0.9 | 0.8 |
| Total | 8.3 | 3.3 | 3.0 |

Source: Hyped for Hopes: Europe's Low Cost Airlines (McKinsey Quarterly, No. 4, 2002)

In Europe, Ryanair has been a leader in the use of the internet for direct sales and 'e-tickets'. In the US Southwest Airlines was an innovator in "e-ticketing", and was also one of the first to initiate bookings on the Internet. VBAs avoid travel agency commissions and ticket production costs: in Canada, WestJet has stated that Internet booking account for approximately 40% of their sales, while in Europe, Ryanair claimed an Internet sales percentage of 91% in March 2002.[14] While most VBA's have adopted direct selling via the internet, the strategy has been hard for FSAs to respond to with any speed given their complex pricing systems. Recent moves by full service carriers in the US and Canada to eliminate base commissions should prove to be interesting developments in the distribution chains of all airlines.

To some degree, VBAs have positioned themselves as market builders by creating point-to-point service in markets where it could not be warranted previously due to lower traffic volumes at higher FSA fares. VBAs not only stimulate traffic in the direct market of an airport, but studies have shown that VBAs have a much larger potential passenger catchment area than FSAs. The catchment area is defined as the geographic region surrounding an airport from which passengers are derived. While an

[14] WestJet estimated that a typical ticket booked through their call centre costs roughly $12, while the same booking through the Internet costs around 50 cents.

FSA relies on a hub-and-spoke network to *create* catchment, low-cost carriers create the incentive for each customer to create their own spoke to the point of departure. Table 3 provides a summary of the alternative airline strategies pursued in Canada, and elsewhere in the world.

**Table 3**

Description of Strategies in the Canadian Airline Industry:[15]

| Strategy | **High Cost, Full Service** | | **Low Cost, No Frills** | | |
|---|---|---|---|---|---|
| Network Type | Hub-and-Spoke, Scheduled Service | Point-to-Point, Scheduled Service | Point-to-Point, Charter/Scheduled | Point-to-Point, Charter | Point-to-Point, Scheduled |
| Characteristics | High Fixed Costs<br>High Labour Costs<br>Inflexible Job Tasks<br>Full Service<br>Multiple Classes<br>High Frequencies | Moderate Fixed Costs<br>Moderate Labour Costs<br>Moderate Job Tasks Flexibility<br>Full Service<br>Multiple Classes<br>Low Frequencies | Low Fixed Costs<br>Moderate Labour Costs<br>Moderate Job Tasks Flexibility<br>Low-end Full Service<br>Single and Multiple Classes<br>Low Frequencies | Low Fixed Costs<br>Low Labour Costs<br>Flexible Job Tasks<br>Low-end Service<br>Single Class (few wider seats)<br>Low Frequencies | Low Costs<br>Lower Labour Costs<br>Flexible Job Tasks<br>No Frills Service<br>Single Class<br>Increasing Frequencies |
| Example | Air Canada<br>American,<br>United,<br>British Airways,<br>JAL | Roots Air-failed in 2001 | Canada 3000,<br>Royal Airlines (pre-merger)-failed in 2001 | Air Transat<br>Skyservice | West Jet<br>CanJet<br>Ryanair<br>Southwest<br>Jet Blue |

### *2.3 Survival of the fittest?*

The trend worldwide thus far indicates two quite divergent business strategies. The entrenched FSA carriers' focuses on developing hub and spoke networks while new entrants seem intent on creating low-cost, point-to-point structures. The hub and spoke system places a very high value on the feed

[15] Adapted from "Air Canada, Turning on the after-burner in Profitable Skies", April 7, 2000, Mark Korol, National Bank Financial.

traffic brought to the hub by the spokes, especially the business traffic therein, thereby creating a complex, marketing intense business where revenue is the key and where production costs are high. Inventory (of seats) is also kept high in order to meet the service demands of business travellers. The FSA strategy is a high cost strategy because the hub-and-spoke network structure means both reduced productivity for capital (aircraft) and labour (pilots, cabin crew, airport personnel) and increased costs due to self-induced congestion from closely spaced banks of aircraft.[16]

The FSA business strategy is sustainable as long as no subgroup of passengers can defect from the coalition of all passenger groups, and recognizing this, competition between FSAs included loyalty programs designed to protect each airline's coalition of passenger groups – frequent travelers in particular. The resulting market structure of competition between FSAs was thus a cozy oligopoly in which airlines competed on prices for some economy fares, but practiced complex price discrimination that allowed high yields on business travel. However, the vulnerability of the FSA business model was eventually revealed through the VBA strategy which (a) picked and chose only those origin-destination links that were profitable and (b) targeted price sensitive consumers.[17] The potential therefore was not for business travelers to defect from FSAs (loyalty programs helped to maintain this segment of demand) but for leisure travelers and other infrequent flyers to be lured away by lower fares.

Figures 2 and 3 present a schemata that help to summarize the contributory factors that propagated the FSA hub-and-spoke system and made it dominant, followed by the growth of the VBA strategy along with the events and factors that now threaten the FSA model.

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[16] Airlines were able to reduce their costs to some degree by purchasing ground services from third parties. Unfortunately they could not do this with other processes of the business.

[17] VBAs will also not hesitate to exit a market if it is not profitable (e.g. WestJet's recent decision to leave Sault St. Marie and Sudbury) while FSAs are reluctant to exit for fear of missing feed traffic and beyond revenue.

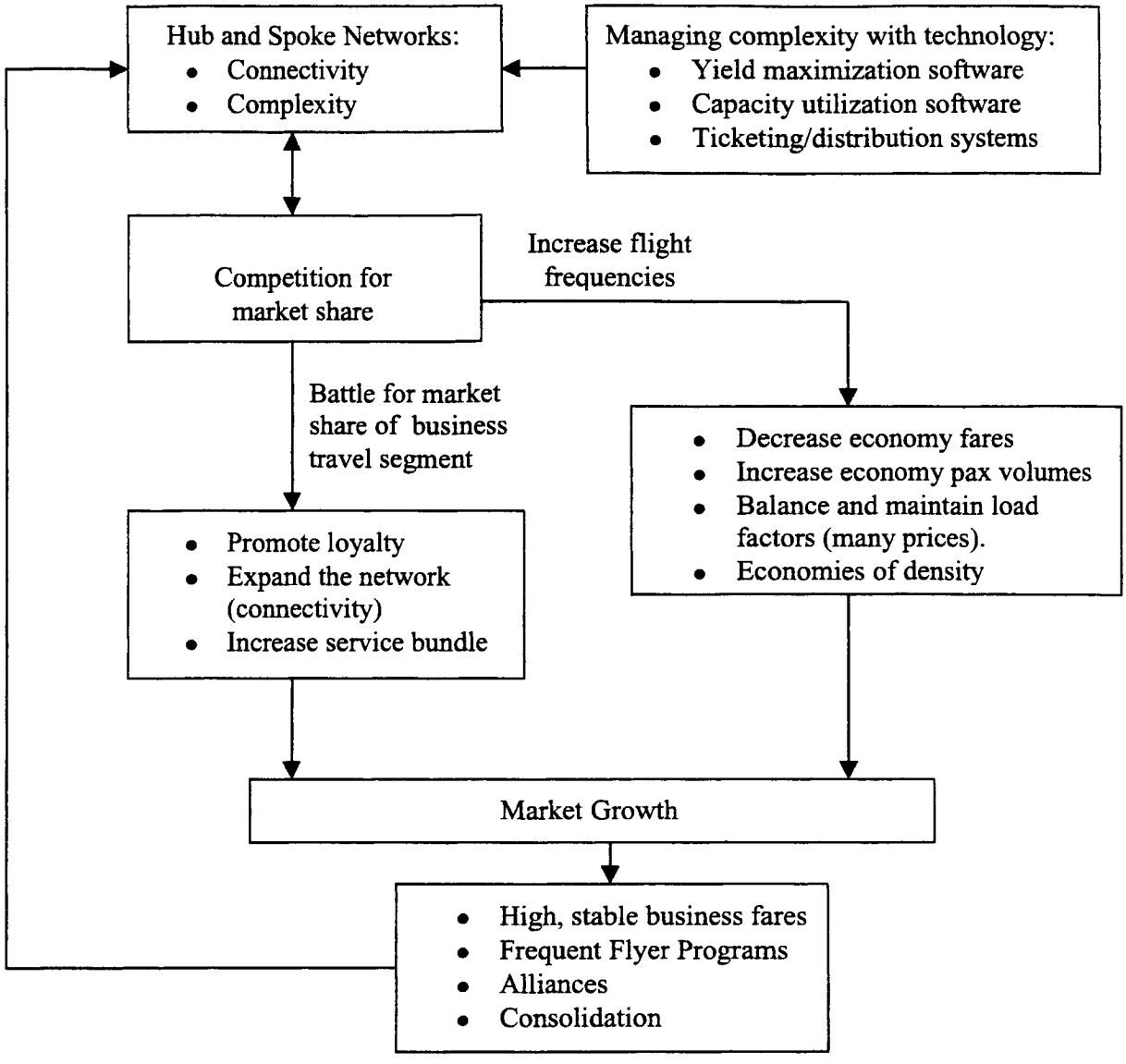


Figure 1
The rise of the FSA hub-and-spoke system

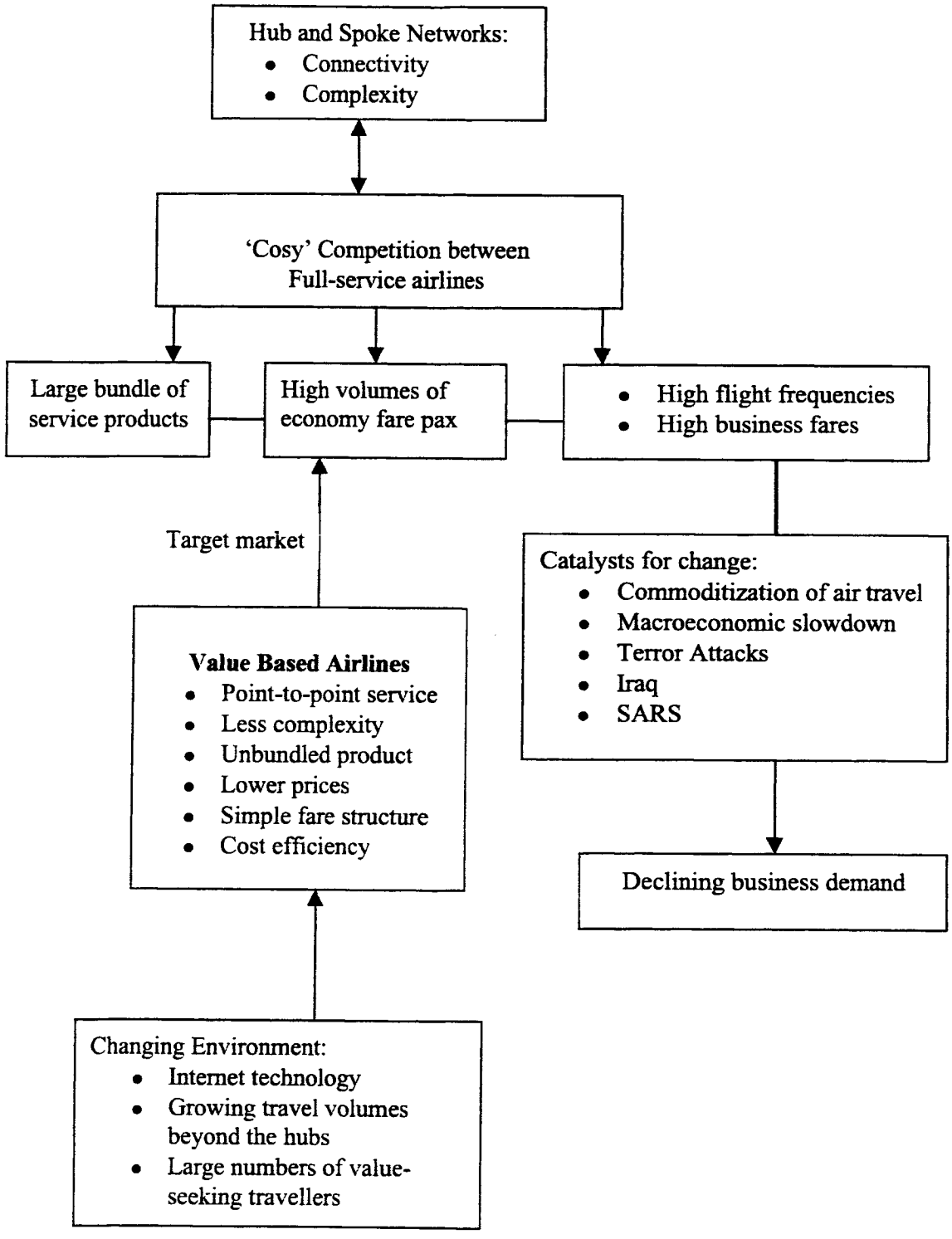


Figure2
Hub-and-spoke networks under threat: the growth of VBA point-to-point networks

### *3. The economics of networks and airline competition*

In this section we set out a simple framework to explain the evolution of network equilibrium and show how it is tied to the business model. The linkage will depend on how the business models differ with respect to the integration of demand conditions, fixed and variable cost and network organization.

Let three nodes $\{\theta_1, \theta_2, \theta_3; (0,0), (0,1), (1,0)\}$, form the corner coordinates of an isosceles right triangle. The nodes and the sides of the triangle may thus represent a simple linear travel network that defines two 'short-haul' travel links $[(\theta_1, \theta_2) (\theta_1, \theta_3)]$ and one 'long-haul' link $(\theta_2, \theta_3)$.

In this travel network, the nodes represent points of entry and exit to/from the network, thus if the network is assumed to be an air travel market, the nodes represent airports rather than cities. This may be important when considering congestion or other factors affecting passenger throughput at airports.

This simple network structure allows us to compare three possible structures for the supply of travel services: a complete (fully connected) point-to-point network (all travel constitutes a direct link between two nodes); a hub-and-spoke network (travel between $\theta_1$ and $\theta_2$ requires a connection through $\theta_2$) and limited (or partial) point-to-point network (Selective direct links between nodes). These are illustrated in figure 3 below.

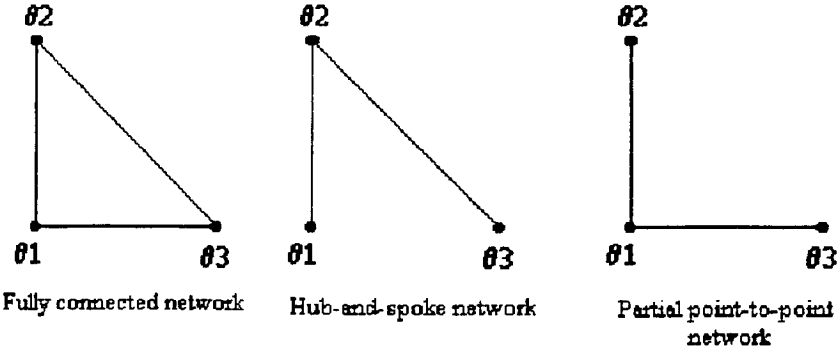


Figure 3: Alternative network structures

In the network structures featuring point-to-point travel, the utility of consumers who travel depends only on a single measure of the time duration of travel and a single measure of convenience. However in the hub-and spoke network, travel between $\theta_1$ and $\theta_3$ requires a connection at $\theta_2$, consequently the time duration of travel depends upon the summed distance $d_{1c3} = d_{12} + d_{23} = 1+\sqrt{2}$. Furthermore, in a hub-and spoke network, there is interdependence between the levels of convenience experienced by travellers. If there are frequent flights between $\theta_1$ and $\theta_2$ but infrequent flights between $\theta_2$ and $\theta_3$, then travellers will experience delays at $\theta_2$.

There has been an evolving literature on the economics of networks or more properly the economics of network configuration. Hendricks et al. (1995) show that economies of density can explain the hub-and-spoke system as the optimal system in the airline networks. The key to the explanation lies in the level of density economies. However, when comparing a point-to-point network they find the hub-and-spoke network is preferred when marginal costs are high and demand is low but given some fixed costs and intermediate values of variable costs a point-to-point network may be preferred. Shy (2001) shows that profit levels on a fully connected (FC) network are higher than on a hub-and-spoke network when variable flight costs are relatively low and passenger disutility with connections at hubs is high. What had not been explained well, until Pels (2000) is the relative value of market size to achieve lower costs per ASM versus economies of density.[18]

Pels et al. (2000) explore the optimality of airline networks using linear marginal cost functions and linear, symmetric demand functions; $MC=1-\beta Q$ and $P=\alpha-Q/2$ where $\beta$ is a returns to density parameter and $\alpha$ is a measure of market size. The Pels model demonstrates the importance of fixed costs in determining the dominance of one network structure over another in terms of optimal profitability. In particular, the robustness of the hub-and-spoke network configuration claimed by earlier authors (e.g. Hendricks et al., 1995) comes into question.

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[18] ASM – available seat mile.

In our three-node network, the Pels model generates two direct markets and one transfer market in the hub-and-spoke network, compared with three direct markets in the fully connected network. Defining aggregate demand as $Q = Q_D + Q_T$, the profits from a hub-and-spoke network, are:

$$\Pi_{HS} = 2\left(P_D Q_D + \frac{1}{2} P_T Q_T\right) - 2\left(Q_D + Q_T - \frac{\beta}{2}(Q_D + Q_T)^2 + f\right) \quad (1)$$

while the profits of a FC network are:

$$\Pi_{FC} = 3\left(P_{FC} Q_{FC} - \left(Q_{FC} - \frac{\beta}{2} Q_{FC}^2 + f\right)\right) \quad (2)$$

More generally, for a network of size n , hub-and-spoke optimal profits are:

$$\Pi_{HS} = (n-1)\left(P_D Q_D + \frac{(n-2)}{2} P_T Q_T\right) - (n-1)\left(Q_D + (n-2)Q_T - \frac{\beta}{2}(Q_D + (n-2)Q_T)^2 + f\right) \quad (3)$$

and FC profits are:

$$\Pi_{FC} = \frac{n(n-1)}{2}\left(P_{FC} Q_{FC} - \left(Q_{FC} - \frac{\beta}{2} Q_{FC}^2 + f\right)\right) \quad (4)$$

Under what conditions would an airline be indifferent between network structure? The market size at which profit maximizing prices and quantities equate the profits in each network structure is:

$$\alpha^* = \frac{\beta(2n-1) + 1 \pm \sqrt{X}}{\beta(2n-1+\beta)} \quad (5)$$

where, $X = [1 - \beta(2n-3)](\beta - 1)[2f\beta(2n-1+\beta) + \beta - 1]$ (6)

The two possible values of $\alpha^*$ implied by (5) represent upper and lower boundaries on the market size for which the hub-and-spoke network and the fully connected network generate the same level of optimal profits. These boundary values are of course conditional on given values of the density

economies parameter ($\theta$) fixed costs (f), and the size of the network (n). These parameters can provide a partial explanation for the transition from FC to hub-and-spoke network structures after deregulation.

With relatively low returns to density, and low fixed costs per link, even in a growing market, the hub-and-spoke structure generates inferior profits compared with the FC network, except when the market size ($\alpha$) is extremely high. However with high fixed costs per network link, the hub-and-spoke structure begins to dominate at a relatively small market size and this advantage is amplified as the size of the network grows. Importantly in this model, dominance does not mean that the inferior network structure is unprofitable. In ($\alpha$,$\beta$) space, the feasible area (defining profitability) of the FC structure encompasses that of the hub-and-spoke structure. This accommodates the observation that not all airlines adopted the hub-and-spoke network model following deregulation.

Where the model runs into difficulties is in explaining the emergence of limited point-to-point networks and the VBA model. It is the symmetric structure of the model that renders it unable to capture some important elements of the environment in which VBAs have been able to thrive. In particular, three important elements of asymmetry are missing. First, the model does not allow for asymmetric demand growth between nodes in the network. With market growth, returns to density can increase on a subset of links that would have been feeder spokes in the hub-and-spoke system when the market was less developed. These links may still be infeasible for FSAs but become feasible and profitable as independent point-to-point operations, providing an airline has low enough costs. Second, the model does not distinguish between market demand segments and therefore cannot capture the gradual commoditization of air travel, as more consumers become frequent flyers. To many consumers today, air travel is no longer an exotic product with an air of mystery and an association with wealth and luxury. There has been an evolution of preferences that reflects the perception that air travel is just another means of getting from A to B. As the perceived nature of the product becomes more commodity-like, consumers become more price sensitive and are willing to trade off elements of service for lower prices.[19] VBAs use their low fares

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[19] To model a such a demand system we need a consumer utility function of the form:
$U = U(Y, T, V) = \gamma V(Y - P)$; where Y represents dollar income per period and $T \in [0,1]$ represents travel trips per period. V is an index of travel convenience, related to flight frequency and P is the delivered price of travel. This

to grow the market by competing with other activities. Their low cost structure permits such a strategy. FSAs cannot do this to any degree because of their choice of bundled product and higher costs.

Third, the model does not capture important asymmetries in the costs of FSAs and VBAs, such that VBAs have significantly lower marginal and fixed costs. Notice that the dominance of the hub-and-spoke structure over the FC network relies in part on the cost disadvantage of a fixed cost per link, which becomes prohibitive in the FC network as the number of nodes (n) gets large. VBAs do not suffer from this disadvantage because they can pick and choose only those nodes that are profitable. Furthermore, FSAs variable costs are higher because of the higher fixed costs associated with their choice of hub-and-spoke network.

### *4. Stability, competition and regulation*

It would seem that with each new economic cycle, the evolution of the airline industry brings about an industry reconfiguration. Several researchers have suggested that this is consistent with an industry structure with an 'empty core', meaning non-existence of a natural market equilibrium. Button (2003) makes the argument as follows. We know that a structural shift in the composition (i.e., more low-cost airlines) of the industry is occurring and travel substitutes are pushing down fares and traffic. We also observe that heightened security has increased the time and transacting costs of trips and these are driving away business, particularly short haul business trips. As legacy airlines shrink and die away, new airlines emerge and take up the employment and market slack.

The notion of the 'empty core' problem in economics is essentially a characterization of markets where too few competitors generate supra-normal profits for incumbents, which then attracts entry. However entry creates frenzied competition in a war-of-attrition game environment: the additional competition induced by entry results in market and revenue shares that produce losses for all the market participants. Consequently entry and competition leads to exit and a solidification of market

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reduces each consumer's choice problem to consumption of a composite commodity priced at $1, and the possibility of taking at most one trip per period. Utility is increasing in V and decreasing in P, thus travellers are willing to trade-off convenience for a lower delivered price. Diversity in the willingness to trade off convenience for would be represented

shares by the remaining competitors who then earn supra-normal profits that once again will attract entry.

While there is some intuitive appeal to explaining the dynamic nature of the industry resulting from an innate absence of stability in the market structure, there are theoretical problems with this perspective.[20] The fundamental problem with the empty core concept is that its roots lie in models of exogenous market structure that *impose* (via assumptions) the conditions of the empty core rather than deriving it as the result of decisions made by potential or incumbent market participants. In particular, for the empty core to perpetuate itself, entrants must be either ill advised or have some unspecified reason for optimism. In contrast, modern industrial organization theory in economics is concerned with understanding endogenously determined market structures. In such models, the number of firms and their market conduct emerge as the result of a decisions to enter or exit the market and decisions concerning capacity, quantity and price.

Part of the general problem of modeling an evolving market structure is to understand that incumbents and potential entrants to the market construct expectations with respect to their respective market shares in any post-entry market. A potential entrant might be attracted by the known or perceived level of profits being earned by the incumbent firm(s), but must consider how many new consumers they can attract to their product in addition to the market share that can appropriated from the incumbent firm(s). This will depend in part upon natural (technological) and strategic barriers to entry, and on the response that can be expected if entry occurs. Thus entry only occurs if the *expected* profits exceed the sunk costs of entry. While natural variation in demand conditions may induce firms to make errors in their predictions, resulting in entry and exit decisions, this is not the same thing as an 'empty core'.[21]

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by distribution for Y, $\gamma$, and V over some range of parameter values. Thus the growth of value-based demand for air travel would be represented by an increase in the density of consumers with relatively low value of these parameters.

[20] The empty core theory is often applied to industries that exhibit significant economies of scale, airlines are thought generally to have limited if any scale economies but they do exhibit significant density economies. These density economies are viewed as providing conditions for an empty core. The proponents however only argue on the basis of FSA's business model.

[21] This has led some to lobby for renewed government intervention in markets or anti-trust immunity for small numbers of firms. However, if natural variability is a key factor in explaining industry dynamics, there is nothing to suggest that governments have superior information or ability to manipulate the market structure to the public benefit.

In the air travel industry, incumbent firms (especially FSAs) spend considerable resources to protect their market shares from internal and external competition. The use of frequent flier points along with marketing and branding serve this purpose. These actions raise the barriers to entry for airlines operating similar business models.

What about the threat of entry or the expansion of operations by VBAs? Could this lead to exit by FSAs? There may be legitimate concern from FSAs concerning the sustainability of the full-service business model when faced with low-cost competition. In particular, the use of frequency as an attribute of service quality by FSAs generates revenues from high-value business travellers, but these revenues only translate into profits when there are enough economy travellers to satisfy load factors. So, to the extent that VBAs steal away market share from FSAs they put pressure on the viability of this aspect of the FSA business model. The greatest threat to the FSA from a VBA is that a lower the fare structure offered to a subset of passengers may induce the FSA to expand the proportion of seats offered to lower fares within the yield management system. This will occur with those VBAs like Southwest, Virgin Blue in Australia and easyjet that do attempt to attract the business traveller from small and medium size firms. However, carriers like Ryanair and Westjet have a lower impact on overall fare structure since their frequencies are lower and the FSA can target the VBAs flights.[22]

While FSAs may find themselves engaged in price and/or quality competition, the economics of price competition with differentiated products suggests that such markets can sustain oligopoly structures in which firms earn positive profits. This occurs because the prices of competing firms become strategic complements. That is, when one firm increases its price, the profit maximizing response of competitors is to raise price also and there are many dimensions on which airlines can product differentiate within the FSA business model.[23]

There is no question FSAs have higher seat mile costs than VBAs. The problem comes about when FSAs view their costs as being predominately fixed and hence marginal costs as being very

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[22] There are some routes in which WestJet does have high frequencies and has significantly impacted mainline carriers. (e.g. Calgary-Abbotsford)

[23] A standard result in the industrial organisation literature is that competing firms engaged in price competition will earn positive economic profits when their products are differentiated.

low. This 'myopic' view ignores the need to cover the long run cost of capital. This in conjunction with the argument that network revenue contribution justifies most all routes, leads to excessive network size and severe price discounting.[24] However, when economies are buoyant, high yield traffic provides sufficient revenues to cover costs and provide substantial profit. In their assessment of the US airline industry, Morrison and Winston (1995) argue that the vast majority of losses incurred by FSAs up to that point were due to their own fare, and fare war, strategies. It must be remembered that FSAs co-exist with Southwest in large numbers of markets in the US.

### *4.1 Competition policy and competition between FSAs and VBAs*

What response would we expect from an FSA to limited competition from a VBA on selected links of its hub-and-spoke network? Given the FSA focus on maximization of aggregate network revenues and a cognisance that successful VBA entry could steal away their base of economy fare consumers (used to generate the frequencies that provide high yield revenues), one might expect aggressive price competition to either prevent entry or to hasten the exit of a VBA rival. This creates a problem for competition bureaus around the world as VBAs file an increasing number of predatory pricing charges against FSAs. Similarly, the ability of FSAs to compete as hub-and-spoke carriers against a competitive threat from VBAs is constrained by the rules of the game as defined by competition policy.

In Canada, Air Canada faces a charge of predatory pricing for its competition against CanJet and WestJet in Eastern Canada. In the US, American Airlines won its case in a predatory pricing charge brought by three VBAs: Vanguard Airlines, Sun Jet and Western Pacific Airlines. In Germany, both Lufthansa and Deutsche BA have been charged with predatory pricing. In Australia, Qantas also faces predatory pricing charges.

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[24] The beyond or network revenue argument is used by many FSAs to justify not abandoning markets or charging very low prices on some routes. The argument is that if we did not have all the service from A to B we would never receive the revenue from passengers who are travelling from B to C. In reality this is rarely true. When FSAs add up the value of each route including its beyond revenue the aggregate far exceeds the total revenue of the company. The result is a failure to abandon uneconomic routes. The three current most profitable airlines among the FSAs, Qantas, Lufthansa and BA, do not use beyond revenue in assessing route profitability.

Morrison (2003) points out three important dimensions of predatory pricing in air travel markets. First, demand complementarities in hub-and-spoke networks lead FSAs to focus on 'beyond revenues'–the revenue generated by a series of flights in an itinerary rather than the revenues generated by any one leg of the trip. FSA's therefore justify aggressive price competition with a VBA as a means of using the fare on that link (from an origin node to the hub node for example) as a way of maximizing the beyond revenues created when passengers purchase travel on additional links (from the hub to other nodes in the network). The problem with this argument is that promotional pricing is implicitly a bundling argument, where the airline bundles links in the network to maximize revenue. However when FSAs compete fiercely on price against VBAs, the price on that link is not limited to those customers who demand beyond travel. Therefore, whether or not there is an intent to engage in predatory pricing, the effect is predatory as it deprives the VBA of customers who do not demand beyond travel.

A second dimension of predatory pricing is vertical product differentiation. FSA's competition authorities to support the view that they the right to match prices of a rival VBA. However, the bundle of services offered by FSAs constitutes a more valuable package. In particular, the provision of frequent flyer programs creates a situation where matching the price of a VBA is 'de facto' price undercutting, adjusting for product differentiation. A recent case between the VBA Germania and Lufthansa resulted in the Bundeskartellamt (the German competition authority) imposing a price premium restriction on Lufthansa that prevented the FSA from matching the VBAs prices.

A third important dimension of predatory pricing in air travel markets is the ability which FSAs have to shift capacity around a hub-and-spoke network, which necessarily requires a mixed fleet with variable seating capacities. In standard limit output models of entry deterrence, an investment in capacity is not a credible threat to of price competition if the entrant conjectures that the incumbent will not use that capacity once entry occurs. Such models utilize the notion that a capacity investment is an irreversible commitment and that valuable reputation effects cannot be generated by the incumbent engaging in 'irrational' price competition. However in a hub-and-spoke network, an FSA can make a credible threat to transfer capacity to a particular link in the network in support of aggressive price competition, with the knowledge that the capacity can be redeployed elsewhere

in the network when the competitive threat is over. This creates a positive barrier to entry with reputation effects occurring in those instances where entry occurs. Such was the case when CanJet and West Jet met with aggressive price competition from Air Canada on flights from Monkton NB to Toronto (Air Canada and CanJet) and Hamilton (WestJet). The FSA defence against such charges is that aircraft do not constitute an avoidable cost and should not be included in any price-cost test of predation. Yet while aircraft are not avoidable with respect to the network, they are avoidable to the extent they can be *redeployed* around the network. If aircraft costs become included in measures of predation under competition laws, this will limit the success of price competition as a competitive response by an FSAs responding to VBA entry.

In the current environment, competition policy rules are not well specified and the uncertainty does nothing to protect competition or to enhance the viability of air travel markets. However there has been increased academic interest in the issue and it seems likely that given the number of cases, some policy changes will be made.[25] Once again, the way in which FSAs have responded to competition from VBAs reflects their network model, and competition policy decisions that prevent capacity shifting, price matching and inclusion of 'beyond revenues' will severely constrain the set of strategies an FSA can employ without causing some fundamental changes in the business model and corresponding network structure.

### *5 So where are we headed?*

In evolution, the notion of selection dynamics lead us to expect that unsuccessful strategies will be abandoned and successful strategies will be copied or imitated. We have already observed FSAs attempts to replicate the VBA business model through the creation of fighting brands. Air Canada created Tango, Zip, Jazz, and Jetz. Few other carriers worldwide have followed such an extensive re-branding. In Europe, British Airways created GO and KLM created BUZZ, both of which have since been sold and swallowed up by other VBAs. Qantas has created a low cost long haul carrier - Australian Airlines. .Meanwhile, Air New Zealand, Lufthansa, Delta and United are moving in the direction of a low price-low cost brand.

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[25] See Ross and Stanbury (2001) for example.

We are also seeing attempts by FSAs to simplify their fare structures and exploit the cost savings from direct sales over the internet. Thus there do seem to be evolutionary forces that are moving airlines away from the hub-and-spoke network in the direction of providing connections as distinct from true hubbing.

American Airlines is using a 'rolling hub' concept, which does exactly as its name implies. The purpose is to reduce costs through both fewer factors such as aircraft and labour and to increase productivity. The first step is to 'de-peak' the hub, which means not having banks as tightly integrated. This reduces the amount of own congestion created at hubs by the hubbing carrier and reduces aircraft needed. It also reduces service quality but it has become clear that the traditionally high yield business passenger who valued such time-savings is no longer willing to pay the very high costs that are incurred in producing them. However, as an example, American Airlines has reduced daily flights at Chicago so with the new schedules it has increased the total elapsed time of flights by an average of 10 min. Elapsed time is a competitive issue for airlines as they vie for high-yield passengers who, as a group, have abandoned the airlines and caused revenues to slump. But that 10-min. average lengthening of elapsed time appears to be a negative American is willing to accept in exchange for the benefits.

At Chicago, where the new spread-out schedule was introduced in April, American has been able to operate 330 daily flights with five fewer aircraft and four fewer gates and a manpower reduction of 4-5%.[26] The change has cleared the way for a smoother flow of aircraft departures and has saved taxi time.[27] It's likely that American will try to keep to the schedule and be disinclined to hold aircraft to accommodate late arriving connection passengers. While this may appear to be a service reduction it in fact may not, since on-time performance has improved.[28]

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[26] American has also reduced its turn around at spoke cities from 2.5 hours previously to approximately 42 minutes.
[27] As a result of smoother traffic flows, American has been operating at Dallas/Fort Worth International Airport with nine fewer mainline aircraft and two fewer regional aircraft. At Chicago, the improved efficiency has allowed American to take five aircraft off the schedule, three large jets and two American Eagle aircraft. American estimates savings of $100 million a year from reduced costs for fuel, facilities and personnel, part of the $2 billion in permanent costs it has trimmed from its expense sheet. The new flight schedule has brought unexpected cost relief at the hubs but also at the many "spoke" cities served from these major airports. *Aviation Week and Space Technology*, Sept 2, 2002 and February 18, 2003.

*In conclusion*

The evolution of networks in today's environment will be based on the choice of business model that airlines make. This is tied to evolving demand conditions, the developing technologies of aircraft and infrastructure and the strategic choices of airlines. As we have seen, the hub-and-spoke system is an endogenous choice for FSA while the linear FC network provides the same scope for VBAs. The threat to the hub-and-spoke network is the threat to bundled product of FSAs. The hub-and-spoke network will only disappear if the FSA cannot implement a lower cost structure business model and at the same time provide the service and coverage that higher yield passengers demand. The higher yield passengers have not disappeared the market has only become somewhat smaller and certainly more fare sensitive, on average.

FSAs have responded to VBAs by trying to copy elements of their business strategy including reduced in-flight service, low cost [fighting] brands, and more point-to-point service. However, the ability of FSA to co-exist with VBA and hence hub-and-spoke networks with linear networks is to redesign their products and provide incentives for passengers to allow a reduction in product, process and organizational complexity. This is a difficult challenge since they face complex demands, resulting in the design of a complex product and delivered in a complex network, which is a characteristic of the product. For example, no-shows are a large cost for FSA and they have to design their systems in such a way as to accommodate the no-shows. This includes over-booking and the introduction of demand variability. This uncertain demand arises because airlines have induced it with service to their high yield passengers. Putting in place a set of incentives to reduce no-shows would lower costs because the complexity would be reduced or eliminated. One should have complexity only when it adds value. Another costly feature of serving business travel is to maintain sufficient inventory of seats in markets to meet the time sensitive demands of business travellers.

The hub-and-spoke structure is complex, the business processes are complex and these create costs. A hub-and-spoke network lowers productivity and increases variable and fixed costs, but these are not characteristics inherent in the hub-and-spoke design. They are inherent in the way

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[28] Interestingly, from an airport perspective the passenger may not spend more total elapsed time but simply more time in the terminal and less time in the airplane. This may provide opportunities for non-aviation revenue strategies.

FSA use the hub-and-spoke network to deliver and add value to their product. This is because the processes are complex even though the complexity is needed for a smaller, more demanding, higher yield set of customers. The redesigning of business processes moves the FSA between cost functions and not simply down their existing cost function but they will not duplicate the cost advantage of VBAs. The network structure drives pricing, fleet and service strategies and the network structure is ultimately conditional on the size and preferences in the market.

What of the future and what factors will affect the evolution of network design and scope? Airline markets with their networks are continuously evolving. What took place in the US ten years ago is now occurring in Europe. A 'modern' feature of networks is the strategic alliance. Alliances between airlines allow them to extend their network, improve their product and service choice but at a cost. Alliances are a feature associated with FSAs not VBAs. It may be that as FSAs reposition themselves they will make greater use of alliances. VBAs on the other hand will rely more on interlining to extend their market reach. Interlining is made more cost effective with modern technologies but also with airports having an incentive to offer such services rather than have the airlines provide them. Airports as modern businesses will have a more active role in shaping airline networks in the future.

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# Regulation in the Air: Price-and-Frequency Caps

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**Abstract**

Despite deregulation on the air-transportation markets, many connections are still operated by a single operator. Regulation is thus a central issue in this industry. There is however a great concern for the (possibly negative) consequences of price regulation on the quality of services. We argue that both aspects should be consider jointly and propose a mechanism that allow to decentralize the optimal structure of services in this industry. The regulatory procedure is robust to the introduction of heterogeneity in the travellers' valuation of the connections' frequency.

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# 1 Introduction

"Maintaining competition in deregulated airlines markets" is, in the words of Meyer and Menzies (2000), a key concern of the air-transportation industry. Despite the deregulation that occurred in the last years, there is still a very low level of competition on the European market. In 1997, namely five years after the adoption of the "third package"[1] by the European Commission, almost 85% of the 336 connections over the French territory were run by one operator and more than 12% by only two. This makes it clear that regulation is a perspective that cannot be ignored.

Regulation of air transportation services cannot escape the quality issue. Economies of scale leads naturally the monopolist to provide connections with a lower frequency than what would be optimal from a social welfare point of view. And in a regulated environment, it might be feared that firms concentrate their efforts on reducing costs at the expense of quality; frequency may thus be reduced and welfare further deteriorated. The specificity of the approach consists in addressing simultaneously both distortions: the distortion in terms of prices and the distortion in terms of frequency. It is shown in this paper that the socially optimal supply of services as caracterised by the price and the frequency can be reached by the means of a simple regulatory mechanism: a price-cap constraint that depends on the frequency of services.

The air-transportation industry is made of a complex network of travel services. Within this network, each of the services is in interaction with the others in order to insure possible connections. Most companies are nevertheless organised according to a star network, that is, with transportation services that connect a central airport (hub) to the periphery (spoke). The generalisation of this "hub-and spokes" system makes the management of each of this services almost independent from the others. As a matter of

[1] 2409/92: Council Regulation of 23 July 1992 on fares and rates for air services (OJ L 240 of 28 August 1992). This is the last step in the european process that implemented full deregulation in the sector.

facts, a large fraction of the passengers may actually pursue its travel and have a connection. However, as long as there is not a unique final destination and passengers are distributed over several connections, there are no reasons to favour a specific arrival time. This is in particular true on the most important routes, for which the frequency of services is quite high. As a result, each of the transportation services can be considered as an independent market.

In the model, we thus focus on a single origin-destination pair. The (aggregate) demand for air transportation services is a function of the price and the frequency of services. Each (Air-)travel translates indeed in both monetary and (waiting-)time costs for the passengers. We first caracterise the first best allocation that can be interpreted as a generalization of the marginal pricing rules. When compared to the standard monopoly regulation problem there is an additional trade-off. An increase in the frequency of services induces an increase in operational costs but also in improvement of consumers' welfare. These benefits are evaluated by using the well-known concept "value of time". It is shown that, if sustainability is not a concern, the optimal allocation is such that the "generalised price" for users is equal to the average transportation costs. A second step of the analysis consist in displaying the choices made by a non-regulated monopolist. The characteristics of the service supplied by the monopolist is compared to the optimal structure introduced before. The study goes on by considering the second-best optimum, a more realistic situation where social welfare is maximised taking into account the sustainability constraint. This is a modified Ramsey-Boîteux problem that takes into account the specificities of the air transportation sector. The model presented here bears several characteristics in common with the literature on quality regulation[2]. The model brings however several new insights that are not explicitly dealt with in this literature. In particular we address the implementation problem for the second-best allocation when quality is taken into account. Regarding the air-transportation

[2]See Laffont and Tirole (1993, chap. 4).

sector, Panzar (1979) is the first to address these questions. The issues of air transportation regulation and public policy are discussed at length by Levine (1987). The closest model to our analysis is a recent contribution by Brueckner and Zhang (2001). Their much more ambitious study calls however for *a priori* assumptions on the demand function that we are able to avoid here.

# 2 The model

The supply of air-transportation services between two airports is caracterised by the pair $(p, f)$ where $p$ denotes the ticket price and $f$ the frequency of the flights. The company has to bear fixed costs $F$ and operational costs. Production costs . The later are directly related to the frequency of connections and the nature of the planes. A one way flight with a plane of capacity $K$ translates into operational costs $C(K)$ on the link that is considered.
In the long run, the company is assumed to adjust the capacity $K$ of the planes to the total traffic observed $X$. The relation $K = X/f$ is considered to hold all along the paper. The framework may however easily be adapted to situation where planes are not used at full capacity.
We also assume that there are increasing returns to scale: the average transportation cost $C(K)/K$ is a decreasing function of the *aircraft* size $K$. This hypothesis is fully backed by empirical data. As an example, for Airbus A320 category, even when we ignore the fact that bigger planes usually allow to reach higher distances, the elasticity with respect to capacity of total consumption per passenger is almost constant at $-0.84$. From a theoretical point of view, this hypothesis brings an explanation to several facts. First, it explains why there are no competitors on the connection considered. Second, it also explains why it is less costly for to company to offer low-frequency services with large airplanes rather than numerous connections with small capacity aircrafts.

The demand in air-transportation services depends on the price $p$ but also

on the frequency of connections $f$. Assuming the ideal departure time to be uniformly distributed along the time interval that *separates* two departures, the average waiting time is equal to $1/2f$. Denote $\nu$ the value of time of the population that is considered. The average (waiting-)time costs for services of "quality" $f$ amounts to $\nu/2f$ for each passengers flying between the two cities.

Let $S(.)$ be the (gross) surplus of the representative travellers, a function of its travel consumption. The net surplus is obtained by taking off all the costs supported by the travellers: ticket price $p$ and time costs $\nu/2f$. We can thus define the demand function as:

$$X(p,f) = \arg\max_X \left\{ S(X) - \left( p + \frac{\nu}{2f} \right) X \right\}. \tag{1}$$

Substitute the demand function into the net surplus to get the indirect utility function:

$$V(p,f) = S[X(p,f)] - \left( p + \frac{\nu}{2f} \right) X(p,f). \tag{2}$$

The identities (1) and (2) display the fact that the unitary costs of the commodity $X$ (one travel) for the passengers amount to the "generalised price" $\widetilde{p} = p + \nu/2f$. In other words, demand is a function of the whole transportation costs and not the sole price $p$. This explains why the observed traffic is also a function of the value of time $\nu$.

# 3 Social Optimum

In this section, we analyse the first-best allocation, that is the allocation that maximizes the social welfare (the sum of consumers' surplus and firm's profits). At this stage the company is not required to break-even. We thus implicitly assume that fixed costs can be financed without efficiency cost trough a subsidy financed from the general budget. Such a solution is usually not considered to be realistic. Nevertheless it provides us with an interesting benchmark.

Total surplus can be expressed as follows:

$$W_1(X,f) = S(X) - \frac{\nu}{2f}X - fC\left(\frac{X}{f}\right) - F \tag{3}$$

where fixed costs, operational costs but also passengers' time costs are substracted from the gross surplus. Differentiating (3) with respect to $X$ and $f$, and rearranging yields the following first-order conditions:

$$S'(X) = C'(K) + \frac{\nu}{2f}, \tag{4}$$

$$\frac{\nu}{2f} = \frac{C(K)}{K} - C'(K). \tag{5}$$

Equation (4) evidences the two components of the marginal cost of an additional passenger. On the one hand, the (standard) marginal cost of production $C'(K)$ as supported by the firm. On the other hand, the time costs $\nu/2f$ supported by this additional passenger. Equation (5) evidences the twofold effect of an increase in frequency. On the one hand, an increase of the operational costs that is proportional to the unit cost of a flight (thus the average transportation cost). This is a consequence of the marginal increase in the number of flights. On the other hand, a marginal decrease in the cost of each flight that follows from the decrease of the capacity $K$. As a result, the hypothesis of capacity adjustment yields to the conclusion that, the optimal (long run) allocation as caracterised by $X$ and $f$ should be such that:

$$S'(X) = \frac{C(K)}{K}. \tag{6}$$

In words, the double *marginal* rule that should govern the choice of $X$ and $f$ results in a rule where the optimal capacity is defined by the *average* costs. Travellers' maximising behaviour implies $S'(X) = p + \nu/2f$. Substituting this expression into (4) and (6) leads to:

$$p = C'(K), \tag{7}$$

$$\widetilde{p} = \frac{C(K)}{K}. \tag{8}$$

Expressions (7) and (8) show respectively that first-best allocation can be decentralized through *(i)* marginal cost pricing and *(ii)* a frequency of connections such that the generalised price $\widetilde{p}$ as supported by the passenger exactly equals the average transportation cost. Interestingly enough, this induces an efficient setting of the transportation services characteristics. The (only) travellers are those for which the transportation costs (including time costs) are smaller than the firms' operational costs.

A consequence of this (optimal) pricing policy is however that the company does not break-even. More precisely, sales will only cover marginal costs and the deficit will amount at least to the fixed costs $F$. Profits may indeed be written as:

$$\Pi = pX - fC(K) - F = fK\left[C'(K) - \frac{C(K)}{K}\right] - F$$

where $C'(K) < C(K)/K$ from the increasing returns to scale assumption. Remark that, the higher the value of time $\nu$ and the higher the traffic level $X$, the bigger the losses. By using (5), the profits of the firm at the first-best optimum can be rewritten as:

$$\Pi = -\frac{\nu}{2f}X - F.$$

As a result, the first-best solution is not feasible if the operator faces a break-even constraint. One has then to consider a second-best solution where prices are set above marginal cost in order to recover all the costs. This question is addressed below.

# 4 Transportation services with a profit maximising monopolist

The first-best allocation has been computed by considering social welfare and fully ignoring the issue of profitability. We know turn to the converse

situation by considering the choices made by a profit-maximising monopolist. The price $p$ and the frequency $f$ will be such that the profit

$$\Pi(p,f) = pX(p,f) - fC(X/f) - F$$

is maximum. This gives rise to the following first-order conditions:

$$\begin{aligned}\frac{\partial \Pi}{\partial p} &= X(p,f) + (p - C'(K))\frac{\partial X}{\partial p} = 0 \\ \frac{\partial \Pi}{\partial f} &= (p - C'(K))\frac{\partial X}{\partial f} - C(K) + \frac{X}{f}C'(K) = 0.\end{aligned}$$

In order to interpret these expressions, it is useful to introduce the price-elasticity of the demand function (in absolute value):

$$\epsilon_{X_p} = -\frac{p}{X(p,f)}\frac{\partial X(p,f)}{\partial p}.$$

This value measures the rate of demand decrease that follows from a one point increase in the price. Note that this parameter depends *a priori* on the price $p$ and the frequency $f$. Since the link between price and frequency are at the center of the questions addressed in this paper, it is useful to study the impact on demand of changes in both parameters. For this purpose, we use equation (1) describing travellers' behaviour to get:

$$\frac{\partial X(p,f)}{\partial f} = -\frac{\nu}{2f^2}\frac{\partial X(p,f)}{\partial p}$$

We can now re-write the FOC to obtain the following characterization of the services supplied by a profit-maximising monopolist:

$$\frac{p - C'(K)}{p} = \frac{1}{\epsilon_{X_p}} \tag{9}$$

$$\frac{\nu}{2f} = \frac{C(K)}{K} - C'(K). \tag{10}$$

Equation (9) shows that the mark-up made by the monopolist is inversely related with the price-elasticity of demand. In words, the more captive the

travellers are, (*i.e.* the less alternatives they have so that they are constrained to pay their ticket "whatever the price"), the higher the profits of the company. Interestingly, this well-known monopoly pricing formula is not modified by the possibility of choosing the frequency of connections. Note however that this does not mean that the price $p$ is independent from the frequency $f$ : the elasticity $\epsilon_{X_p}$ is indeed a function of both parameters.
It may appear surprising that equation (10) does not differ from the equation (5) that defines optimal frequency at the first-best. Again, the unchanged *rule* does not mean that *value* will be the same in both cases. While the average waiting time should always be equal to the difference between the mean cost and the marginal cost, these costs are evaluated for different values of the capacity $K = X/f$. It is nevertheless remarkable to find unchanged the rule that governs the choice of $f$. Even the unregulated monopolist sets $f$ by taking into account, not only the impact of $f$ on its own costs but also the impact of $f$ on travellers surplus (because of its effect on the travel demand).

# 5 Traffic and frequency complementarity

Since Spence (1975) we know that a monopolist may under- or over- supply quality (with respect to what would be socially optimum) depending on the complementarity or substitutability of the quantity and the quality. By definition, $X$ and $f$ will be complement if the social benefits of quality increase with the number of travellers or _ this is equivalent_ if the marginal benefits of one travel increase with the frequency. There will be substitutability otherwise. Formally complementarity is defined by:

$$\frac{\partial^2 W}{\partial X \partial f} = \frac{\partial^2 W}{\partial f \partial X} = \frac{\partial}{\partial f}\left[p - C'(K)\right] \geq 0 \qquad (11)$$

In other words, $X$ and $f$ are complements (resp. substitutes) if the difference between the marginal willingness to pay for a ticket and the marginal cost of a travel is increasing with the frequency (resp. decreasing). The behaviour of

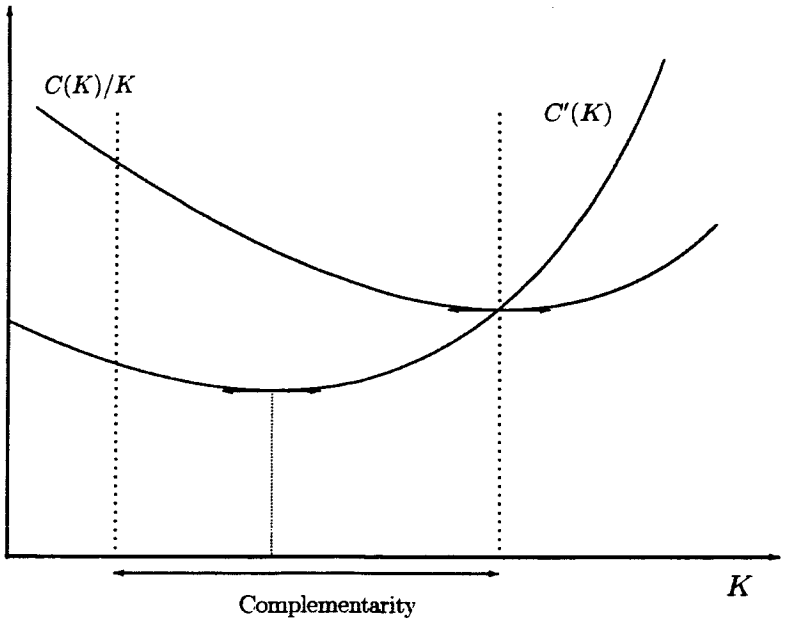
the firm will however depend on its capacity to extract the consumer surplus rather than its value. This leads us to rewrite equation (11) by using equation (5) that characterises frequency to obtain:

$$\frac{\partial^2 W}{\partial f \partial X} = -\frac{K}{f}\frac{d}{dK}\left[\frac{C(K)}{K} - C'(K)\right].$$

This equation makes it clear that demand and frequency are complements if the difference between the mean cost and the marginal cost is decreasing with the plane capacity. Observe that this same difference governs the frequency choice both at the social optimum and at the profit maximising equilibrium. Given a frequency of connections $f$, the demand $X$ and thus the capacity of the aircrafts $K$ will be lower in the monopoly case than at the first-best. In case of complementarity, the average waiting time is decreasing with $K$. Thus the monopolist will set a *lower* frequency than what would be socially optimum. In case of substitutability, the frequency would be *higher*.
Note that complementarity of $X$ and $f$ is actually a fair assumption since

$$\begin{aligned}\frac{d}{dK}\left[\frac{C(K)}{K} - C'(K)\right] &= \frac{1}{K}\left(C'(K) - \frac{C(K)}{K}\right) - C''(K) \\ &= -\frac{\nu}{2X} - C''(K).\end{aligned}$$

Thus, in order to have substitutability, one should have a (strongly) decreasing marginal cost: $C''(K) < -\nu/(2X)$. As soon as it is not the case, traffic and frequency will be complement and the monopolist will set a frequency $f$ below what would be socially optimum. This is the assumption made in the remaining part of the paper.




# 6 Second-best

We now turn to the so-called second-best, where social welfare

$$W_2(p,f) = V(p,f) + \Pi(p,f) = S(X) - \frac{\nu}{2f}X - fC\left(\frac{X}{f}\right) - F$$

is maximised under the constraint that the firm may break-even. Observe that, even without any fixed costs $F$, the assumption made earlier according to which the mean cost $C(K)/K$ is decreasing implies that the price should be higher than the marginal cost for the firm to break-even.

Denote $L$ the Lagrangian expression associated with this problem while $\lambda$ is the multiplier of the break-even constraint. We obtain the following first order conditions:

$$\frac{\partial L}{\partial p} = \left[S'(X) - \left(p + \frac{\nu}{2f}\right)\right]\frac{\partial X}{\partial p} - X(p,f)$$

$$+(1+\lambda)\left[X(p,f)+(p-C'(K))\frac{\partial X}{\partial p}\right]=0,$$

$$\frac{\partial L}{\partial f} = \left[S'(X)-\left(p+\frac{\nu}{2f}\right)\right]\frac{\partial X}{\partial f}-\frac{\nu}{2f^2}X(p,f)$$
$$+(1+\lambda)\left[(p-C'(K))\frac{\partial X}{\partial f}-C(K)+\frac{X}{f}C'(K)\right]=0.$$

By using equation (1) that describes travellers behaviour and the various notations introduced above, this system can be simplified to get

$$\frac{p-C'(K)}{p} = \frac{\lambda}{1+\lambda}\frac{1}{\epsilon_{X_p}}, \tag{12}$$

$$\frac{\nu}{2f} = \frac{C(K)}{K}-C'(K). \tag{13}$$

Equation (12) shows that the rule that governs the setting of prices at the second-best is not modified when time costs are taken into account. This is the standard Ramsey formula. Since the distortion that follows from a price set above the marginal cost increases with the elasticity of demand, the mark-up should be inversely related to this price elasticity. It is set in such a way that the overall distortion is minimised and the firm can recover all its costs which importance is measured by the shadow price $\lambda$.

Equation (13) is unchanged with respect to equation (5) obtained for the first-best. This does not come as a surprise since the equation governing the choice of frequency was already the same for the un-regulated monopolist. Remind that this does not mean that the frequency will be identical. In particular, if $X$ and $f$ are complements, the frequency set by a regulated monopolist should be higher than the frequency that would be chosen by a profit-maximising firm. (and lower than the first-best level).

A last remark should be made regarding equation (13). That the multiplier $\lambda$ is not part of it does not mean that the frequency $f$ is independent of the fixed costs $F$. If costs increase, then $\lambda$ increases since the mark-up increases in order to cover this additional costs. Thus the price $p$ (at second-best) is

an increasing function of $F$. More precisely, the price $p$ and the frequency $f$ at the second-best optimum less and less differ from the values set by a profit-maximising firm (thus more and more differ from the first-best values). In other words, a state-owned firm which maximizes social welfare subject to the break-even constraint but which is relatively inefficient (and thus has to finance high fixed costs) does not really differ from a profit maximising firm.[3]

# 7 Implementation: price-and-frequency cap

The implementation of the (second-best) optimal allocation raises several difficulties. On the one hand the regulator does not usually have a sufficient knowledge of the market in order to decide what should be the characteristics (price and frequency) of each city-pair connection. On the other hand, without any competition and control, the air-transportation company is expected to offer services with (too) high tariffs at a (too) low frequency. This will push down the welfare of inhabitants and the profits of the firms in the concerned cities; and thus hinder the economy of an entire region. Note that a publicly owned firm would not solve for this problem. As soon as managers' reward is linked with the firm performance _which appear to be desirable feature_ the company will adopt a strategy that aims to maximise profits. The problem is thus fundamentally linked with the working of markets, or, in the words of Spence, with the "divergence between private and social benefits". Again, facts speaks from themselves. On the Paris-Toulouse connection, for example, in the years that follow deregulation in Europe, the number of passengers raised by one half, the average capacity of the flights has been halved and the number of moves tripled. The aim of the mechanism proposed here is

[3]If in addition to fixed costs $F$, operational costs $C(K)$ are also higher for a public owned firm, it might be more convenient for the consummers to face a profit-maximising firm.

precisely to give the "right incentives" to the firms where deregulation has not allowed markets to escape a monopolistic situation. However, as already mentioned, the regulator should not (and cannot) substitute herself to the company because of obvious asymmetric information problems. We show that it is nevertheless possible to decentralise the optimal (second-best) solution by the means of a price-cap conjugated with a suitable "quality reward".

Assume that the firm maximizes its profits subject to the following "price-and-frequency" cap constraint:

$$\tilde{p} = p + \frac{\nu}{2f} \leq \overline{p}. \tag{14}$$

The company is free to use its knowledge of demand in order to choose the price $p$ and the frequency $f$ on the considered market provided that the generalised price that travellers have to support does not exceed an upper bound $\overline{p}$. As a result, the quality of services dispose the upper limit for prices. Put it the other way: tariff setting determines a minimum frequency level. The first-order conditions of this maximisation program can be written as:

$$\begin{aligned} X(p,f) + (p - C'(K))\frac{\partial X}{\partial p} - \mu &= 0 \\ (p - C'(K))\frac{\partial X}{\partial f} - C(K) + \frac{X}{f}C'(K) + \mu\frac{\nu}{2f^2} &= 0 \end{aligned}$$

where $\mu$ is the Lagrange multiplier associated to the "price-and frequency" cap constraint (14). Assume that the regulator fix the upper bound $\overline{p}$ in such a way that

$$\mu = X^* / (1 + \lambda)$$

where $X^*$ is the demand at the second-best optimum. The monopolist will find it profitable to fix $p$ and $f$ such that:

$$\begin{aligned} \frac{p - C'(K)}{p} &= \left(1 - \frac{\mu}{X}\right)\frac{1}{\epsilon_{X_p}} = \frac{\lambda}{1+\lambda}\frac{1}{\epsilon_{X_p}} \\ \frac{\nu}{2f} &= \frac{C(K)}{K} - C'(K). \end{aligned}$$

In order to implement the optimal solution, it is thus sufficient to compel the firm to offer services such that their "generalised prices" do not exceed their second-best optimal values.

Such a regulatory mechanism could appear to be an artificial (and useless) rewriting of the problem if the regulatory body would not have the necessary information to fix $\overline{p}$. Despite its simplicity, the mechanism proposed here appears to be perfectly implementable. The optimal solution can be reached by the means of an iterative mechanism inspired by Vogelsang and Finsinger (1979) that is based on the sole book-keeping data.[4] In the remaining part of the paper, we study how it extends to an heterogeneous population.

# 8 Heterogeneity of characteristics and regulation

The outlined regulatory process ability to work when travellers are heterogeneous is the focus of the present section. To do this we consider a population of travellers with value of time $\nu$ distributed over $[0, +\infty[$, according to the density function $g(\nu)$ and the cumulative distribution function $G(\nu)$. The aggregate demand is thus given by

$$X(p, f) = \int_0^{+\infty} x_\nu(p, f)\, g(\nu)\, d\nu$$

where $x_\nu(p, f)$ is the individual demand of a traveller with a value of time $\nu$, as defined by equation (1). Note that, at this stage, the value of time $\nu$ is the only characteristic that differs across individuals.

Taking into account the very fact that the company cannot offer different connection frequencies to the passengers, the computation of the social

[4] More precisely, one need to observe traffic, prices and profits at each period and for each connection. The principle consists in adjusting the coefficient of the constraint at each period and one can show that this coefficient will converge to their optimal values. On this mechanisms and their limits, see Laffond and Tirole (1993).

optimum as defined by the first-best leads to almost unchanged conclusions. Indeed, the optimal allocation is now defined by the system

$$S'(x_\nu) = C'(K) + \frac{\nu}{2f} \quad all\ \nu, \tag{15}$$

$$\frac{\overline{\nu}}{2f} = \frac{C(K)}{K} - C'(K). \tag{16}$$

where $\overline{\nu} = \int_0^{+\infty} \nu\,(x_\nu/X)\,g(\nu)\,d\nu$ is a weighted average of the value of time. In words equation (15) states that *all travellers*[5] should see the marginal benefits of their travel to equate the sum of the marginal cost of production $C'(K)$ and their own (waiting-) time costs $\nu/2f$. Equation (16) substitutes for equation (5) in defining the optimal frequency $f$. It states that the mean value of time $\overline{\nu}$ to be considered is an average that weights the value of time proportionally to the relative number of travel $x_\nu/X$. In other words, the more people travel, the more their value of time impact on the value $\overline{\nu}$ considered by the social planner.

Interestingly enough, this optimal allocation can still be implemented by the means of a marginal pricing rule. More precisely, the travellers' behaviour as defined by (1) implies that $S'(x_\nu) = p + \nu/(2f)$ all $\nu$. Thus $p = C'(K)$ and $f$ defined by equation (16) will exactly decentralise the optimum allocation. Consequently, under the assumption of this model the heterogeneity does not introduce any source of inefficiency in the setting of the transportation services. Whatever its value of time $\nu$, each traveller use transportation services up to (and no more than) a level such that her marginal benefits exactly equates the total (*i.e.* production and time) marginal cost. Note that, in contrast to the representative agent case, each traveller will now support a different generalised price, $\widetilde{p}_\nu$ :

$$\widetilde{p}_\nu = p + \frac{\nu}{2f} = \frac{C(K)}{K} + \frac{\nu - \overline{\nu}}{2f}.$$

In words, the generalised price is equal to the *average* cost plus the difference between the their own (waiting-) time and the average one.

[5] Whatever their value of time $\nu$.

As long as the company sticks to linear tariffs, the profit-maximising structure of services is defined by the pair $(p, f)$ that solves for the system:

$$\begin{aligned} X(p,f) + (p - C'(K))\frac{\partial X}{\partial p} &= 0 \\ (p - C'(K))\frac{\partial X}{\partial f} - C(K) + \frac{X}{f}C'(K) &= 0 \end{aligned}$$

Price is thus defined by the standard formula

$$\frac{p - C'(K)}{p} = \frac{1}{\epsilon_{X_p}},$$

while the frequency obeys an equation unchanged in its form:

$$\frac{\widehat{\nu}}{2f} = \frac{C(K)}{K} - C'(K).$$

In contrast to what happens when the regulator sets for $f$, the average value of time considered is not proportional to frequency of use of air-transportation services. The firm rather consider the profitability of each type so that $\widehat{\nu}$ is defined by:

$$\begin{aligned} \widehat{\nu} &= \int_0^{+\infty} \nu \frac{\partial x_\nu / \partial p}{\partial X / \partial p} g(\nu)\, d\nu \\ &= \int_0^{+\infty} \nu \frac{x_\nu}{X} \frac{\epsilon_\nu}{\epsilon_{X_p}} g(\nu)\, d\nu, \end{aligned}$$

where

$$\epsilon_\nu = \frac{p}{x_\nu}\left(\frac{-\partial x_\nu}{\partial p}\right).$$

This does mean that the value of time is biased "toward" the more sensitive types, *i.e.* the types with the higher price elasticity $\epsilon_\nu$.

Not surprisingly, the second-best allocation corresponds to a solution the lies in-between the first-best allocation and the profit-maximising one. More precisely, price and frequency are defined by the system:

$$\begin{aligned} \frac{p - C_X}{p} &= \frac{\lambda}{1+\lambda}\frac{1}{\epsilon_{X_p}}, \\ \frac{\tilde{\nu}}{2f} &= \frac{C(K)}{K} - C'(K). \end{aligned}$$

where $\lambda$ is the "usual" Lagrange multiplier associated with the break-even constraint and the value of time $\tilde{\nu}$ is a weighted sum of the value already introduced $\hat{\nu}$ and $\overline{\nu}$:

$$\tilde{\nu} = \frac{\overline{\nu} + \lambda\hat{\nu}}{1+\lambda}.$$

Such a result sheds *a priori* a very negative light on the applicability of the regulatory mechanism proposed above. Information considerations makes it obvious that such a value cannot be assumed to be known by the regulator. It makes thus more striking the following result: the second-best allocation will be (exactly) implemented by a monopolist submitted to the regulatory constraint:

$$\tilde{p} = p + \frac{\overline{\nu}}{2f} \leq \overline{p}$$

where $\overline{\nu}$ is the mean value of time over the plane passengers. The proposed mechanism does not require the regulator to have more knowledge than the "social" or "average" value of time.

# 9 CONCLUSION

The optimal tariffs and optimal frequency of air transportation services is determined. Despite the complex interaction between price and quality (frequency), the optimal price is exactly defined by the Ramsey-Boîteux rule. The optimal frequency should be such that the time costs equate the difference between the average and the marginal costs. If quantity and frequency are strategic complements, a monopoly will setup the prices above the socially optimal value and the frequency below the socially optimal level.

In order for the optimal structure of services to be set up by the monopolist, incentives should be given both to decrease price and to increase frequency. This is possible, if the transportation company is submitted to a regulatory constraint that bears on the generalised transportation costs, that this the sum of the ticket price and (the monetary value of) the time

costs. Implementation requires only book-keeping data and the knowledge of the social or average value of time. It appears thus possible to propose a regulatory scheme that deal with both price and quality aspects.

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# INDUSTRY CONSOLIDATION AND FUTURE AIRLINE NETWORK STRUCTURES IN EUROPE

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**Abstract**

In the current downturn in demand for air travel, major airlines are revising and rationalising their networks in an attempt to improve financial performance and strengthen their defences against both new entrants and traditional rivals. Expansion of commercial agreements or alliances with other airlines has become a key reaction to the increasingly competitive marketplace. In the absence, for regulatory reasons, of cross-border mergers these are the principal means by which the industry can consolidate internationally. The failure of airlines such as Sabena and Swissair has also enforced restructuring at some of Europe's busier airports. This paper analyses the developments which have been taking place and attempts to identify the implications for airline network structures and the function of different hub airports.

Airlines have rationalised their networks by withdrawing services that feed the hubs of rival alliances. New links have however been created that are made feasible by the alliance support. The range of services available to passengers in long-haul markets to/from Europe is evaluated before and after recent industry reorganisation.

Hubs are crucial to interlink the route networks of partners in an alliance. However, duplication between nearby hub airports that find themselves within the same airline alliance can lead to loss of service at the weaker locations. The extent to which the alliance hubs in Europe duplicate or complement each other in terms of network coverage is assessed and this methodology also enables the optimal partnerships for 'unattached' airlines to be identified. The future role of the various European hubs is considered under different scenarios of global alliance development.

The paper concludes by considering possible longer-term developments. In an environment where the low-cost carriers will provide a major element of customer choice, it is suggested that the traditional airlines will retrench around their hubs, surrendering many secondary cities to the low-cost sector. Further reduction in the number of alliances could threaten more of the European hubs. For both regulatory and commercial reasons, the end result may be just one airline alliance - so recreating in the deregulated market the historic role of IATA.

**Keywords**
airline, airport, network, hub, alliance, competition

## 1. Introduction

The downturn in demand for air travel that followed the terrorist attacks of September 11th 2001, magnified by the weak economic conditions in many major countries and more recently the looming war against Iraq and the SARS epidemic have made the last two years unhappy ones for most of the world's airlines.

For almost the first time, demand for air travel cannot be assumed to follow an ever rising trend. Airlines have reacted by cutting back the weaker parts of their network and operations and aiming for more co-operation and consolidation within the industry to curb excess capacity. Many of these changes were overdue and it is difficult to attribute them directly to the downturn following September 11th. It has however created a business environment where more radical measures can be implemented.

The major airlines have moved to strengthen their position in the marketplace by consolidating operations under one brand. In some cases this involved the merger or take-over of an independent rival (for example, SAS acquired its Norwegian rival Braathens and American Airlines has taken-over the ailing TWA). Franchising, whereby one airline licences its product and identity to another is an alternative method for the major carriers to extend their brand presence while leaving the commercial risk with the franchisee (Denton & Dennis, 2000). Other secondary forms of collaboration include joint operations and code-sharing agreements which may be organised on an ad-hoc route by route basis.

One of the most important developments in the global arena is the emergence of international airline alliances (Hanlon, 1999). Examples are the Star Alliance, which includes Lufthansa and United amongst others or SkyTeam which is based around Air France and Delta. These aim to extend the reach of an individual airline network by linking it with services of partner carriers. This increases the number of city pairs that can be served compared to the airlines operating individually, enables joint scheduling and marketing, combination of frequent flier programmes, combined purchasing and sharing of services and infrastructure. In a downturn of demand, alliances also enable consolidation of capacity, at both the route and network level.

Alliances, mergers, franchising and code sharing arrangements all have the effect of reducing the number of carriers operating at an airport which has the potential to diminish competition and increases the risk to airport operators and communities should the dominant operator change strategy or go out of business. This paper aims to investigate the impact of this re-shaping of the airline industry on airline networks in Europe. Specific attention is given to the likely winners and losers among airports from current airline commercial developments and future strategies are discussed.

## 2. Changes in long-haul coverage

The greatest downturn in demand since September 2001 has come in intercontinental markets such as the North Atlantic and Europe-Middle East. This has accelerated the rationalisation by many airlines of their long-haul services. In Europe, too many small countries have attempted to maintain a national 'flag carrier' with an intercontinental presence. The larger airlines often had several

airports in their home country from which they flew long-haul. It is generally less efficient to split long-haul services between hubs and airlines had already started addressing this problem prior to September 11th, with Swissair moving long-haul routes from Geneva to Zurich and BA deciding to concentrate on Heathrow at the expense of Gatwick (Halstead, 2001).

Tables 1 and 2 consider the change in long-haul service at European airports from Summer 2000 (generally acknowledged to be the high-point of the aviation industry) to Summer 2003. Table 1 takes only the cities with a daily service by the major hub airline (including code-shares). This is a good yardstick of the principal route network, being the minimum frequency necessary in most markets to compete with the strongest airlines (including those with hubs outside Europe). Multi-stop services are included as long as there is no aircraft change involved.

It can be seen that four major airline hubs dominate long-haul services in Europe (BA-London Heathrow, AF-Paris CDG, KL-Amsterdam and LH-Frankfurt). These have all strengthened their position over the last three years and now have a very similar level of service with between 42 and 46 daily long-haul flights by the local airline. In some cases, smaller aircraft are used than previously. BA has run-down Gatwick and moved services to Heathrow with no net growth. Air France has expanded rapidly at Paris CDG, particularly increasing the frequency of services to Latin America. KLM has likewise at Schiphol upgraded a number of sub-daily routes (mainly to Africa and Latin America) to a daily frequency. Lufthansa remains heavily focused on the North Atlantic and Asia. Zurich has conventionally been the 'number five' long-haul hub and narrowly remains so, although with less than half the coverage of the big four. Swiss has nevertheless reinstated much of the old Swissair long-haul network although continued heavy losses may not make this sustainable for very much longer. Iberia at Madrid is the other one to watch - with a doubling of daily frequencies to 16 in the last three years, it is the strongest gateway to Latin America. Of the remaining airports, Brussels has suffered badly following the demise of Sabena and Copenhagen also appears to be declining. Munich and Vienna have shown modest expansion.

Table 2 includes all long-haul points served, which offers a broader perspective. In some cases these are services by other airlines, elsewhere they are sub-daily routes by the hub major. Many secondary Asian points are served only by the foreign carrier and Caribbean points are often served by quasi-charter airlines, especially in Germany, Italy and the Netherlands. It can be seen that the total long-haul network has not increased much, as airlines are tending to focus on higher frequencies to major points rather than maximising the number of places with direct service. Total network coverage has declined everywhere except London Heathrow and Munich over the last three years. Munich is still growing albeit slowly. London Heathrow has benefited from the decimation of Gatwick long-haul operations - where the total network has halved, the biggest decline of any featured airport including Brussels (where Sabena went bankrupt!). Brussels network to Africa has been maintained but with many small foreign airlines often providing low-frequency multi-stop service. Asian and North Atlantic coverage has been badly hit however. Zurich and Rome have also seen significant declines.

It is probable that the underlying reduction in demand is fairly even throughout Europe but some airlines have benefited more than others from cut-backs by the weaker players. This has enabled Air France and Lufthansa to gain market share as some of the traffic that used to pass through Gatwick, Brussels, Zurich, Copenhagen and Rome is spilled elsewhere. KLM is fighting hard to stay in the big league while BA is carrying fewer passengers in total but more via Heathrow.

Table 1
Daily long-haul services by major hub airline in first week of July (including code-shares)

| Airport (Airline) | Year | North America | Latin America | Africa | Asia Pacific | Total |
|---|---|---|---|---|---|---|
| London Heathrow (BA) | 2000 | 14 | - | 3 | 17 | 34 |
| | 2003 | 18 | 1 | 6 | 17 | 42 |
| London Gatwick (BA) | 2000 | 11 | 1 | 2 | - | 14 |
| | 2003 | 4 | 1 | - | - | 5 |
| Paris CDG (AF) | 2000 | 15 | 2 | 6 | 11 | 34 |
| | 2003 | 15 | 8 | 9 | 14 | 46 |
| Amsterdam (KL) | 2000 | 16 | 1 | 4 | 10 | 31 |
| | 2003 | 18 | 6 | 7 | 14 | 45 |
| Frankfurt (LH) | 2000 | 18 | 2 | 3 | 15 | 38 |
| | 2003 | 20 | 3 | 3 | 17 | 43 |
| Munich (LH) | 2000 | 5 | - | - | - | 5 |
| | 2003 | 7 | - | - | 1 | 8 |
| Zurich (SR/LX) | 2000 | 12 | 1 | 1 | 9 | 21 |
| | 2003 | 9 | 1 | 1 | 7 | 18 |
| Milan Malpensa (AZ) | 2000 | 8 | - | 1 | 1 | 10 |
| | 2003 | 7 | 1 | 1 | 2 | 11 |
| Rome Fiumicino (AZ) | 2000 | 4 | - | 1 | 1 | 6 |
| | 2003 | 4 | - | 1 | 1 | 6 |
| Madrid (IB) | 2000 | 3 | 5 | - | 1 | 8 |
| | 2003 | 4 | 11 | - | 1 | 16 |
| Brussels (SN) | 2000 | 7 | - | 1 | 1 | 9 |
| | 2003 | 1 | - | 1 | - | 2 |
| Copenhagen (SK) | 2000 | 4 | - | - | 4 | 8 |
| | 2003 | 4 | - | - | 2 | 6 |
| Vienna (OS) | 2000 | 2 | - | - | 1 | 3 |
| | 2003 | 2 | - | - | 4 | 6 |

Source: Compiled from OAG data

Lufthansa has launched an innovative means of providing long-haul service away from its main hub airports in Germany. This involves using a long-range Airbus A320 configured in an all business class layout. Current routes include Dusseldorf-New York and Dusseldorf-Chicago. Such a strategy will only work where there is sufficient high yield business traffic to maintain a reasonable load factor on an everyday basis however.

Table 2
Long-haul points served by all airlines at any frequency in first week of July

| Airport | Year | North America | Latin America | Africa | Asia Pacific | Total |
|---|---|---|---|---|---|---|
| London Heathrow | 2000 | 19 | 5 | 15 | 49 | 88 |
| | 2003 | 24 | 14 | 20 | 47 | 105 |
| London Gatwick | 2000 | 29 | 17 | 17 | 8 | 71 |
| | 2003 | 19 | 9 | 5 | 3 | 36 |
| Paris CDG | 2000 | 20 | 14 | 30 | 40 | 104 |
| | 2003 | 18 | 15 | 27 | 43 | 103 |
| Amsterdam | 2000 | 20 | 22 | 14 | 42 | 98 |
| | 2003 | 24 | 20 | 14 | 37 | 95 |
| Frankfurt | 2000 | 30 | 20 | 18 | 57 | 125 |
| | 2003 | 33 | 18 | 20 | 51 | 122 |
| Munich | 2000 | 10 | 6 | 7 | 12 | 35 |
| | 2003 | 10 | 4 | 9 | 15 | 38 |
| Zurich | 2000 | 13 | 4 | 19 | 27 | 63 |
| | 2003 | 11 | 3 | 17 | 19 | 50 |
| Milan Malpensa | 2000 | 10 | 13 | 13 | 17 | 53 |
| | 2003 | 8 | 14 | 11 | 17 | 50 |
| Rome Fiumicino | 2000 | 10 | 11 | 14 | 30 | 65 |
| | 2003 | 8 | 6 | 11 | 29 | 54 |
| Madrid | 2000 | 8 | 19 | 5 | 8 | 40 |
| | 2003 | 8 | 16 | 5 | 8 | 37 |
| Brussels | 2000 | 9 | - | 22 | 11 | 42 |
| | 2003 | 6 | - | 20 | 5 | 31 |
| Copenhagen | 2000 | 6 | 2 | 2 | 10 | 20 |
| | 2003 | 6 | 2 | 2 | 9 | 19 |
| Vienna | 2000 | 4 | - | 4 | 24 | 32 |
| | 2003 | 4 | - | 3 | 23 | 30 |

Source: Compiled from OAG data

### 3. Dependence upon a single airline or alliance group

Rather than negotiating with a number of airlines on an equal basis, airports are increasingly likely to find they now have one very powerful customer. Hub airports have for some years tended to become natural monopolies as the hub airline captures almost all the transfer demand and hence will be able to support much higher frequencies than would be justified by the local traffic alone - in some cases the routes would not exist if it were not for the connection traffic. This makes it very difficult for a competitor to survive unless they are flying from a hub at the other end of the route. For example, Lufthansa accounts for 61% of scheduled flights at Frankfurt. In the US, more extreme concentrations are to be found, particularly at the medium sized hubs: USAirways has 88% of flights at Charlotte and Northwest 80% at Detroit (Airline Business, 2000). Taking a route example, Lufthansa and Alitalia operated one daily flight each between Frankfurt and Turin in 1989. By 1997 this had increased to four flights per day but they were all by Lufthansa.

This trend has been exacerbated by airline alliance development (Morrish & Hamilton, 2002). The key hub to hub trunk links are seeing a rapid increase in operations. For example, Amsterdam-Detroit which was not served at all prior to the KLM/Northwest Alliance now has 4 flights per day by Boeing 747 or DC10; Frankfurt-Chicago has gone from 2 flights per day to 4 and Copenhagen-Munich from 3 to 6. Airports and routes which do not fit neatly into the alliance groupings are liable to see their service reduced. For example, United has pulled off Washington-Zurich to concentrate on its links with Lufthansa at Frankfurt while Delta, an Air France partner has similarly axed Washington-Frankfurt. SAS used to serve Hong Kong (now a oneworld hub) from Copenhagen but this has now lost service altogether in favour of Star Alliance connections via Bangkok using Thai, or Frankfurt using Lufthansa. Duplication is also likely to be eliminated over time (for example, Delta dropped its Frankfurt mini-hub to concentrate on links with partner Air France at Paris CDG instead). The net result is that the share of traffic held by the dominant alliance at a particular airport tends to be growing rapidly while rival alliances re-deploy output elsewhere.

This poses a potential problem for airport operators. Many airports have traditiona lly been proud of the range of airlines serving their facility and will make great effort to attract another brightly coloured tailfin onto their apron. In the United States, airport expansion has often hinged around airline requirements. Airlines have also been successful in extracting generous terms from airports by playing them off against each other to be the chosen location for hub expansion. With many airports under local government control, there is a vested interest in bringing employment to the area and obtaining the greatly improved communication links, that could never be justified on the basis of local demand but can be supported on the back of the hub traffic (Small, 1997).

In Europe, airlines are trimming the large number of point to point services they historically operated from places other than their major hub. Even at the major hubs, the number of intercontinental points receiving a direct service is often diminishing as airlines re-structure around high frequency links to the key overseas hubs, with secondary cities reached through connections on partner airlines. For example, 20 years ago, SAS used to serve 36 intercontinental points from Copenhagen, many only once or twice a week with several intermediate stops; it now serves only eight but as most of these operate at least daily, more flights are actually made in total.

## 4. Potential winners and losers among European cities and airports from international airline alliance formation

Most of the global alliances contain one partner in each major region of the world, which consequently defines the key hubs. In Europe however, there is much more duplication within each alliance's coverage. The presence of many international boundaries and the historic constraints these have posed to traffic rights have created a different pattern of airline networks to the United States. Many airlines have ended up dominating a number of airports in their home country, although these are not necessarily all operated as hubs. There is thus considerable repetition in existing airline networks (e.g. British Airways can carry a passenger from Frankfurt to the US via London Heathrow, London Gatwick or Manchester), before one starts looking at the impact of alliances. US experience would suggest there are too many secondary hubs or 'focus cities' in Europe and the financial performance of these is generally poor compared to the primary hubs. The only rationale for major airlines to maintain these dispersed operations is because of capacity constraints at the

major airports (e.g. Heathrow, Frankfurt) which prevent consolidation of operations there, or as a defensive tactic to deter a rival from invading their 'back-yard'. The alliance groupings have led to further overlap and the post-September 11th downturn, together with expansion by low-cost new entrants such as Ryanair, is likely to spell the end for some of the weaker hubs.

Table 3 shows the extent to which the various combinations of European hub airports duplicate each other or serve distinct markets within each alliance group. The analysis takes only European routes which have at least 3x per weekday non-stop service by the alliance partners from the named hub. This is the minimum frequency necessary to achieve a full spread of connections. Only locations with 20 or more such routes are included as viable major hubs (giving 20 European hubs in total at 19 airports, Heathrow featuring in both the oneworld and Star listings). Under these criteria, the table shows the number of points that are served from each pair of hubs in the network (e.g. Frankfurt and Munich have 44 European destinations in common for the Star Alliance) and the number that are unique to that hub (e.g. the Frankfurt/Frankfurt entry shows there are 9 European points that are only served by the Star Alliance from Frankfurt). The total entry represents the total number of European destinations served from Frankfurt by the Star Alliance (65). This is not simply a total of the other entries as there are obviously some points that are served from more than two of the listed hubs.

In the Star Alliance, the Lufthansa hubs at Frankfurt and Munich have the dominant position, as indicated in Table 3(a). There is considerable overlap between these two but Lufthansa operate them in tandem due to capacity constraints at Frankfurt. The SAS hub at Copenhagen adds some additional coverage mainly in Scandinavia. Over the last decade, Copenhagen's traffic has stagnated and SAS has reduced its long-haul presence to the benefit of Lufthansa. However, SAS is now planning to expand again in this arena. Austrian's hub at Vienna however is almost completely duplicated by Frankfurt (26 common routes out of 30). Vienna's main emphasis is in Eastern Europe-Western Europe where it is the strongest hub with the exception of Frankfurt. Whereas Austrian would be a clear asset to any other alliance it is difficult to identify its role in Star! Stockholm Arlanda is important as a niche gateway to the Swedish domestic market while the London Heathrow presence is comprised of 14 European trunk routes plus 8 UK and Ireland points where bmi British Midland has the main Star Alliance presence. Heathrow is likely to be maintained as a toehold in the largest European market and an irritation to oneworld. In summary then, Vienna looks superfluous as a hub to the Star Alliance and Copenhagen is in a less than comfortable position regarding long-haul services.

Table 3
European network coverage
Number of European airports with at least 3x per weekday service from each hub/pair of hubs

(a) Star Alliance

| | Frankfurt | Munich | Copenhagen | Stockholm | Vienna | London LHR | Dusseldorf | TOTAL |
|---|---|---|---|---|---|---|---|---|
| Frankfurt | 9 | | | | | | | |
| Munich | 44 | 4 | | | | | | |
| Copenhagen | 21 | 19 | 12 | | | | | |
| Stockholm | 9 | 7 | 18 | 16 | | | | |
| Vienna | 26 | 21 | 17 | 8 | 3 | | | |
| London LHR | 15 | 12 | 12 | 7 | 12 | 6 | | |
| Dusseldorf | 19 | 18 | 14 | 7 | 15 | 7 | 0 | |
| TOTAL | 65 | 49 | 42 | 35 | 30 | 22 | 20 | 116 |

(b) oneworld

| | Madrid | London LHR | Barcelona | London LGW | Helsinki | TOTAL |
|---|---|---|---|---|---|---|
| Madrid | 7 | | | | | |
| London LHR | 12 | 11 | | | | |
| Barcelona | 29 | 12 | 3 | | | |
| London LGW | 9 | 15 | 7 | 9 | | |
| Helsinki | 2 | 5 | 2 | 2 | 14 | |
| TOTAL | 40 | 36 | 34 | 27 | 20 | 90 |

(c) SkyTeam

| | Paris CDG | Lyon | Milan MXP | Rome FCO | Paris ORY | TOTAL |
|---|---|---|---|---|---|---|
| Paris CDG | 25 | | | | | |
| Lyon | 23 | 4 | | | | |
| Milan MXP | 21 | 13 | 1 | | | |
| Rome FCO | 17 | 10 | 20 | 4 | | |
| Paris ORY | 12 | 12 | 3 | 2 | 10 | |
| TOTAL | 61 | 31 | 30 | 29 | 24 | 90 |

(d) Others with at least 20 routes at 3x per day

| | Amsterdam (KLM) | Zurich (Swiss) | Brussels (SN) | TOTAL |
|---|---|---|---|---|
| Amsterdam (KLM) | 14 | | | |
| Zurich (Swiss) | 31 | 3 | | |
| Brussels (SN) | 25 | 20 | 4 | |
| TOTAL | 51 | 36 | 31 | 60 |

Source: Compiled from OAG, December 2002

Table 3(b) shows that oneworld has more limited European coverage, mainly due to the poor level of frequencies that can be operated from Heathrow and Gatwick. oneworld needs Finnair and Iberia to cover the extremities of the region, which they do effectively - Iberia is now the strongest carrier in Mediterranean Europe, although the Barcelona hub is essentially a smaller version of its Madrid operation. The main scope for rationalisation must however come from British Airways' diverse presence in the UK. Gatwick is being cut back drastically (Air Transport World, 2000) and at Manchester BMI is launching a major expansion now the second runway is open (British Midland Industry Affairs, 2000) which is likely to put further pressure on BA. Nevertheless, half the routes from Heathrow and Gatwick are still duplicated despite BA's recent reorganisation and many of these destinations are also served by BA from Birmingham or Manchester. The main stumbling block for oneworld is that Heathrow is full-up and cannot operate as an effective hub to rival Frankfurt.

In the case of SkyTeam, Air France has created in the last few years a tremendously powerful hub at CDG with still more growth potential. Alitalia does not add much to the alliance however: Table 3(c). With a split hub between Milan Malpensa and Rome as well as a residual operation at Milan Linate, despite dominating a major European market, Alitalia is not a strong partner. Malpensa, once envisaged as Alitalia's rival to Munich and Zurich now contributes little to CDG in the alliance network and Rome with its single airport and better domestic coverage may once again become the major Italian hub. Air France arguably maintains too many bases in France. Paris Orly is likely to see its function as a domestic airport progressively eroded as the CDG hub powers ahead, although they will be anxious to keep any rivals out of the French capital. It is also unlikely that both Lyon and Clermont Ferrand (where Air France has acquired a small but efficient operation through the take-over of Regional Airlines) can remain as duplicated regional hubs in the longer term, only 150 km apart (Citrinot, 2000).

Two other alliances have featured in the past: KLM and Northwest's 'Wings' grouping and Qualiflyer based around Swissair. Although still one of the top three hubs, KLM has seen its strong position in Europe eroded in the last three years. It has lost alliance and code-share links with carriers such as Alitalia, Braathens and Eurowings; succumbed to low-cost competition on routes such as Stansted and Belfast and cut services such as Nice from 3x per day to 2x per day. Qualiflyer has now disintegrated following the bankruptcy of Swissair but Swiss and SN Brussels still retain viable European hubs - with better coverage than Alitalia or Austrian! Swiss is coming back quite rapidly as a serious force in the long-haul arena also and could prove an attractive alliance partner. The future role of SN is less clear although Brussels is about the only 'spare' hub airport in NW Europe where there remains a general shortage of capacity. In Switzerland itself, Crossair's substantial presence at Euroairport Basle/Mulhouse and Geneva adds little to Swissair's network coverage and although some of these routes may be viable on a point-to-point basis, it is likely that much of this capacity could be more lucratively employed from an enlarged Zurich airport.

An interesting exercise is to allocate the non-aligned partners to the three major alliances and investigate where the best fit lies (Table 4). It is also possible to see how existing alliance members such as Austrian or Iberia might be better off in a different alliance. It can be seen that oneworld would be the optimal partnership in terms of European network fit for all the non-aligned airlines, principally due to the poor existing coverage of BA's Heathrow hub. KLM is least suited to Star and although there is considerable duplication with Air France's Paris CDG hub, it still adds a

worthwhile 14 points to the SkyTeam alliance which appears to be KLM's current avenue for discussions. Swiss and SN add little value to anyone except oneworld. If all three of these airlines joined oneworld it would increase its European coverage by 20 airports to 110 points (still behind Star). If Swiss and SN only joined oneworld it would add 11 airports, still behind Star and a combined SkyTeam/KLM.

Table 4
Coverage added by non-aligned airlines when combined with major alliances
Number of European airports with at least 3x per weekday service

| Points added to | Amsterdam (KLM) | Zurich (Swiss) | Brussels (SN) |
|---|---|---|---|
| Frankfurt (Star) | 14 | 3 | 6 |
| Star Alliance TOTAL | 9 | 1 | 4 |
| London LHR (oneworld) | 25 | 14 | 12 |
| oneworld TOTAL | 15 | 8 | 4 |
| Paris CDG (SkyTeam) | 17 | 7 | 3 |
| SkyTeam TOTAL | 14 | 4 | 2 |

Source: Compiled from OAG, December 2002

Table 5 amplifies the changing position in the short-haul coverage of the major European hubs. Frankfurt and Paris CDG are forging well ahead while Amsterdam slips back. Munich and Madrid are rising in importance at the expense of Brussels and Zurich although it is noticeable that the overall picture in short-haul markets is one of growth despite the current parlous state of the aviation industry.

Table 5
Change in European coverage of major hubs since 1999
Number of European airports with at least 3x per weekday service from each hub

| Hub | 1999 routes | 2002 routes | Change |
|---|---|---|---|
| Frankfurt (Star) | 53 | 65 | +12 |
| Paris CDG (SkyTeam) | 49 | 61 | +12 |
| Amsterdam (KLM) | 69 | 51 | - 18 |
| Munich (Star) | 42 | 49 | + 7 |
| Copenhagen (Star) | 36 | 42 | + 6 |
| Madrid (oneworld) | 29 | 40 | +11 |
| London LHR (oneworld) | 31 | 36 | + 5 |
| Zurich (Swiss) | 41 | 36 | - 5 |
| Stockholm (Star) | 36 | 35 | - 1 |
| Barcelona (oneworld) | * | 34 | NA |
| Brussels (SN) | 50 | 31 | - 19 |
| Lyon (SkyTeam) | 20 | 31 | +11 |
| Milan MXP (SkyTeam) | 30 | 30 | 0 |
| Vienna (Star) | 28 | 30 | + 2 |
| Rome FCO (SkyTeam) | 26 | 29 | + 3 |
| London LGW (oneworld) | 28 | 27 | - 1 |
| Paris ORY (SkyTeam) | 24 | 24 | 0 |
| London LHR (Star) | 20 | 22 | + 2 |
| Dusseldorf (Star) | * | 20 | NA |
| Helsinki (Star) | 21 | 20 | - 1 |
| EuroAirport (Swiss) | 21 | * | NA |

* less than 20 routes operated 3x per weekday
Source: Compiled from OAG data

## 5. Future of the global alliances and implications for European hubs

The future development of the global airline alliances has potentially significant implications for the role of different hub airports in Europe and around the world. To date, the alliance groupings have been in a continual state of flux and we are unlikely to have reached the final form yet (Agusdinata & de Klein, 2002). The level of integration within many of the alliances is far from perfect however and it is quite possible that airlines within the same alliance will continue to compete in the way they have always done, paying little regard to the strategies of their supposed partners!

Within the current alliances, the odds of United surviving now look considerably better than six months ago. The Star Alliance is also about to gain US Airways which has restructured fairly successfully (Travel Trade Gazette, 2003). This is likely to strengthen the hand of Lufthansa in Europe as more North Atlantic capacity is flown to Star hubs. However, the future of Virgin Atlantic is one of the big unknowns. Despite being 49% owned by Star member Singapore Airlines, Virgin has remained resolutely outside the major groupings, instead favouring a block space agreement with Continental. Current interest focuses on the scope for a bmi-Virgin merger which would give Star a serious presence at London Heathrow and create a formidable rival to BA (Noakes, 2003). SAS has recently questioned whether it should be continuing in the long-haul

market and may be the first of the smaller European flag carriers to reduce to a purely short-haul network, feeding other alliance partners with longer distance traffic (Campbell, 2003).

KLM and Northwest have to decide whether they will expand to create the much vaunted 'Wings' alliance and find some suitable Asian and Latin American partners (there are carriers in these regions that may not be entirely happy in their existing alliances). This would be a perfectly viable grouping, competitive with the other three and would maximise consumer choice and the number of parallel hubs that can be maintained.

It now seems more likely however that SkyTeam will absorb KLM-Northwest, along with Continental. As Delta, Northwest and Continental have created a three-way alliance in the US, the international partnerships are likely to combine also. This is a serious risk for KLM as Air France's major hub at CDG is too near and too similar for both to prosper. Paris is always likely to be the bigger and more attractive market to serve in Europe than Amsterdam and one can envisage Northwest and Continental refocusing there. Alitalia is struggling to find a role in long-haul services and this also should strengthen the hand of Air France. The other possible destination for Virgin Atlantic would be SkyTeam, if bmi becomes a rival North Atlantic operator at Heathrow. However, it is fairly inconceivable that SkyTeam would wish to use London as a hub.

Another possible switch of alliances involves KLM abandoning Northwest and moving to oneworld. The fit between KLM and BA is relatively good in Europe and with Heathrow capacity constrained and the Gatwick strategy failed, BA might well prefer to promote Amsterdam as a third major hub to Paris and Frankfurt. This would appear to offer the best future for Amsterdam and for maintaining all the major European hubs in the longer term under an outcome of three global alliances. It is not inconceivable that KLM and Northwest could both move to oneworld as Northwest has reasonable synergy with American on long-haul routes, if not an ideal fit domestically. If BA misses out on KLM than Swiss is likely to be its preferred option for filling oneworld's gap in mainland Europe. However, although Swiss badly needs a partnership, it is doubtful that anyone will wish to take them on while their finances are still far in the red.

It is difficult to see an obvious route to two global alliances from the current position. This would seem to require the failure or merger of one of the six US international carriers. A combined Delta-Continental-United (with Air France and Lufthansa in Europe) might balance against American-Northwest-US Airways (with BA and KLM in Europe) but requires splitting the existing partnerships.

A more likely scenario where mergers start to occur between major airlines is that some airlines will then find themselves in two alliances and to overcome competition concerns or local monopolies in certain parts of the world (e.g. Australasia where Qantas is likely to dominate), the fair and easy solution is to merge the alliances so that we return to one industry alliance (IATA by any other name) where all the carriers co-operate with each other. This avoids smaller airlines being disadvantaged and would favour the smaller hubs and the less coordinated or multi-airline hubs such as London over the one-airline dominant hubs such as Frankfurt.

**6. Airline service at second-tier cities**

It is probable that less air service will be provided at the medium sized cities by the traditional national flag carriers in the future. These do not offer the network synergies of the main hubs and are exposed to competition from low-cost airlines when traffic is mainly 'point to point'. Where there is room for conventional service, it is increasingly likely to be provided by foreign airlines, for whom it is a 'spoke' point or specialist regional operators using small aircraft.

Table 6 analyses the change in scheduled services at Birmingham and Belfast International over the last three years. It can be seen that BA has reduced frequencies at Birmingham (and down-sized aircraft, so capacity reduction is even greater), as have most of the other traditional carriers. The low-cost sector has grown from 4 flights per day to 26. At Belfast International, the eclipse of the traditional airlines is almost total. Whereas BA and British Midland still dominated services here as recently as three years ago, they have moved what is left of their Northern Ireland operation to Belfast City, surrendering Belfast International to easyJet.

The low-cost airlines will maintain a reasonable level of direct air service from such cities at competitive fares. They may not be profitable to the airport operator however due to their unwillingness to pay normal airport charges. The other shortcoming is that they do not provide the global accessibility of a conventional hub link, as flights cannot be booked through the GDS, there is no through pricing or schedule co-ordination. This makes low-cost services almost unusable for connecting journeys.

Table 6
Service at Birmingham and Belfast International July 2000 and July 2003

| Airline | Birmingham 2000 | Birmingham 2003 | Belfast Intl 2000 | Belfast Intl 2003 |
|---|---|---|---|---|
| British Airways* | 83 | 70 | 22 | |
| British Midland* | 14 | 10 | 12 | |
| British European | 26 | 27 | | |
| Other Traditional | 29 | 28 | 1 | 1 |
| Total Traditional | 152 | 135 | 35 | 1 |
| easyJet | | | 7 | 33 |
| Ryanair | 4 | 3 | | |
| My Travel Lite | | 16 | | 2 |
| bmibaby | | | | 6 |
| Fresh Aer | | 7 | | |
| Total Low-cost | 4 | 26 | 7 | 41 |
| Overall Total | 156 | 161 | 42 | 42 |

* including franchises and code-shares
Source: Compiled from OAG data

The traditional airlines have favoured airports which have kept the low-cost carriers out - this usually requires either a restricted runway or high user charges. For example, British Airways have launched services this Spring from London City and it remains the only London airport other than Heathrow to be served by most of the European national carriers. London City's runway is too short

to handle 737 jets. Other examples include Southampton, chosen for expansion by British European (Flybe) who have been chased out of many of their traditional markets and Manchester, where there is only a minimal low-cost presence, receiving new BA services.

**7. Conclusion**

The difficult business conditions of the last two years have led to some retrenchment of long-haul services from European airports. Certain low frequency destinations have been discarded in favour of higher frequencies on the trunk routes. The four largest airlines have widened the gap with the rest by continuing to expand intercontinental services at their major hub airports. The greatest cut-backs have been by British Airways at London Gatwick - as part of the airline's 'future size and shape' review and Brussels where only part of Sabena's long-haul service has been replaced by other carriers. Overall however, most of the smaller national carriers continue to stubbornly hang-on in the long-haul market even though many of them are losing large amounts of money in doing so. Swiss has recreated much of the former Swissair network although it has little unique coverage compared to the larger airlines. Iberia is perhaps the only carrier outside the big four that has a clear and defendable niche in long-haul operations with its extensive Latin American network.

Within Europe, most of the hubs have actually expanded in the last three years. One of the few losers is KLM at Amsterdam, which has become isolated from many of its former feeder partners such as Eurowings, Braathens and Alitalia. SN at Brussels is also a pale shadow of the former Sabena operation. Even airlines which have decided to reduce their long-haul presence have maintained their short-haul networks, such as BA at Gatwick and SAS at Copenhagen.

The low-cost airlines currently have only about 15% of the intra-European market but this is rising rapidly. In the UK and Ireland they are now over 30% of short-haul scheduled traffic - higher than in the US domestic market where Southwest has been operating for 30 years! It seems likely that the natural market share of low-cost airlines operating 'point to point' services, often from secondary airports may be around a third. Although some of this traffic is new growth, it means that the traditional airlines are going to have to review their short-haul strategies and withdraw from markets where they do not have a strong competitive position and do not require long-haul feed. The example of Belfast International shows how a medium sized market can be dominated by the low-cost carriers and other places where the majors are likely to be squeezed include Birmingham, London Gatwick, Brussels, Geneva, Paris Orly, Milan and Nice.

Hubs are not going to go away however. Indeed, for the majors they remain crucial to maintain some competitive advantage over the low-cost new entrants and to feed the long-haul flights for which demand is much more dispersed. The main strategic response of the major airlines to changing industry conditions has been to group themselves into international alliances. This only brings efficiencies however if accompanied by some rationalisation and identification of complementary roles. Europe continues to have too many airlines attempting to operate hubs in close proximity to each other and certain locations such as Vienna, Milan Malpensa and Barcelona add little to their relevant alliance and appear to be prime candidates for hub withdrawal.

For the cities which find their airport marginalised in terms of alliance strategy or de-hubbed as a result of airline industry consolidation, the economic consequences are potentially severe. As well

as losing direct employment there is a penalty in terms of accessibility to the rest of Europe and the world. Brussels, for example, saw its level of air service collapse on the demise of Sabena. This then makes the city less attractive as a location for business, leading potentially to a spiral of decline. In the US, Boeing recently moved its corporate headquarters from Seattle to Chicago, citing the much better level of non-stop air service available there. Whereas once geographical patterns of demand determined the configuration of airline networks, now it is the network strategies of airlines that can have a profound effect on geographical patterns of industrial location and economic activity.

Although the current downturn has produced relatively few changes in the European airline industry, several significant developments lie around the corner. The EU is about to start negotiating air services agreements with outside countries to replace the old bilaterals and there are strong signs that national ownership rules will disintegrate. The biggest restructuring may still be yet to come.

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# Application of Core Theory to the Airline Industry

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**Abstract**

Competition in the airline industry has been fierce since the industry was deregulated in 1978. The proponents of *deregulation* believed that more competition would improve efficiency and reduce prices and bring overall benefits to the consumer. In this paper, a case is made based on *core theory* that under certain *demand* and *cost* conditions more competition can actually lead to harmful consequences for industries like the airline industry or cause an *empty core* problem. Practices like monopolies, cartels, price discrimination, which is considered *inefficient allocation* of resources in many other industries, can actually be beneficial in the case of the airline industry in bringing about an *efficient equilibrium.*

**Keywords:** empty core, demand, cost, equilibrium, unrestricted contracting, competition, airline industry.

## Introduction

US Airline industry is considered a highly competitive industry. However, despite receiving $5.0 billion in direct assistance from the U.S. government in 2001, the financial stability of the U.S. domestic airline industry remains substantially in doubt. The recent spate of bankruptcies filings, first by U.S. Air and then by United airlines, leads one to wonder whether competition is essentially good for the airline industry or will ultimately prove destructive to the airline industry. Clearly, the terrorist attacks of September 11, 2001 have had a serious impact on the industry. However, the industry, particularly the major carriers, was headed toward financial distress prior to the terrorist attacks. For the quarter ended June, 2001, the industry posted an operating loss of $70 million, as compared to an operating profit of in excess of $3,000 million the prior year (Linenberg and Flemming, 2001). Various explanations, ranging from labor issues to weak business plans have been offered as reasons for the current woes of the U.S. Airline industry.

In this paper we offer a theoretical explanation for the problems faced by the airline industry based on core theory. According to core theory in some industries, like the airline industry, excess competition can lead to an empty core problem or lack of a stable equilibrium. The notion that competition in the airline industry may be destructive for the airline industry is further strengthened by what happened in the US airline industry immediately after deregulation in the 80's. At that time price-cutting in the industry was extreme, most firms in the industry were losing money even though buyers wanted the product and were willing to pay higher than prevailing prices. The cumulative losses incurred by the industry exceeded the profits previously earned since the industry's inception. Several carriers failed and ceased operations including such high profile operators as Pan American Airways and Eastern Airlines.

Specifically, core theory suggests that, under some conditions, non-competitive practices may in fact have an efficiency-enhancing role in the sense of making both producers and consumers better off. Core theory also clarifies the notion of efficient competition and cooperation - that agents in a market may simultaneously cooperate and compete at the same time.

The paper is organized as follows. In the second section we provide a brief review of terminology and definitions for introducing Core Theory. The third section provides an applied framework so that the abstract concepts of Core Theory are related to standard notions of market organization. In the fourth section, we identify some symptoms of an empty core and relate it to the airline industry. Section 5 look at how the airlines have dealt with the empty core problem in the industry. Section 6 concludes with some policy implications.

## Terminology and Definitions

Core Theory concepts are closely related to many standard economics concepts. To keep the exposition simple, we do not discus these issues. The following definitions are necessary for understanding Core Theory. A numerical illustration and industry examples are included with the definitions.

*Avoidable cost:* The firm in the industry has the option of avoiding this cost. For example in the shipping industry the ship can decide to sail or not to sail and hence can avoid the cost associated with sailing (this decision is separate from cost of purchasing the ship). Similarly in the airline industry the aircraft may decide not to fly and can avoid fuel and other costs associated with flying (this decision is separate from the decision to acquire the aircraft).

*Sunk cost: Expenditure* which cannot be recovered. The cost of purchasing a ship or an aircraft can be considered sunk cost.

*Divisible vs. Indivisible demand:* Divisible demand refers to situations where demand can be broken down into separate units. For example in ocean liner shipping where small packets are shipped or as in the case of airlines where each seat on the aircraft can be considered a separate unit which can be sold at different prices. Whereas in the case of indivisible demand it is not possible to divide demand into different units as in the case of bulk shipping.

*Empty core*: Situation where there is no stable equilibrium. In some industries competition leads to an empty core problem.

In general the essential theoretical ideas of core theory can be set forth in this way.

1. There are a group of *n* individuals (or firms) in a market; some of whom are buyers and others are sellers. They can all trade with each other in a single market, or in sub markets, or may decide not to trade at all.

2. The buyers and sellers can measure the *gains from trade*. For the buyer it is the maximum amount the buyer is willing to pay for the quantities purchased less the amount actually paid. For the seller, it is the amount actually received less the amount the seller would have been willing to accept.

   Following Telser (1994), assume that there are three individuals and the first two are potential buyers of a widget and the third is a seller. The seller S has a valuation of \$10 for the widget. Buyer 1 has a reservation price of \$12 for the widget and buyer 2 has a reservation price of \$15. Let x denote the return to the seller and y1 and y2 denote the returns to the buyers, respectively. In case the seller sells the widget, he would settle for no less than \$10 which is his option value, so that x $\mu$10. For the potential buyers, y1 $\mu$ 0 and y2 $\mu$ 0 because each can refuse to make a purchase and thereby can ensure a net gain of zero.

3. The buyers and sellers can contract with each other and form groups called *coalitions* to maximize their gains from trade. Such a process of contracting can be either unrestricted or restricted depending on the nature of the Industry. What the members of the coalitions get is called an *allocation*.

   With three members, there are a total of $2^3 - 1 = 7$ possible coalitions, excluding the coalition with no members. These are {S}, {B1}, {B2}, {S,B1}, {S,B2}, {B1,B2}, {S,B1,B2}. Coalitions with single members are called *singletons* and coalition with all members is called the *grand coalition*.

4. An allocation is *dominated* if some members of the coalitions can do better for themselves by leaving one coalition and joining another coalition. If the members cannot do better by leaving their existing coalition then the allocation is undominated.

5. A buyer or a seller would be member of a coalition as along as they can do at least as well as they could in any other coalition (it is important to point out that deciding not to trade or being alone is also a possible coalition).

   The approach is to consider all possible coalitions of traders, recognizing that any coalition of traders will only participate in the market as a whole if and only if they can do at least as well as they could in another coalition. In the decision of a member as to which coalition to join, the maximum payoff available in all other coalitions provides the lower bound.

   Core theory considers all possible coalitions, including singleton coalitions. An implication is that, if a coalition forms instead of singletons, we can surmise that all the members believed that they were better off than they were being alone (pareto-optimal).

6. If we have a coalition with all the buyers and sellers in it (called the *grand coalition*) then it means that the each buyer and seller feel that this is the coalition which would maximize their gains otherwise they would not be in the coalition.

7. The grand coalition should therefore offer to each buyer and seller at least as much as they could get in any other coalition they can form i.e., it should be a undominated allocation. The allocation from each possible coalition therefore imposes a lower bound on the payoff for each member, which must be satisfied for the grand coalition to exist.

   Since we include all possible grouping – i.e., singletons, 2-person, 3-person etc. till n-person coalitions, the grand coalition should satisfy the constraints imposed by all coalitions.

8. If there exists no other coalition, which can make at least one person better off without making another person worse off, then economists call such a situation "*Pareto Optimum*". An allocation is an *efficient* allocation if it is a Pareto optimal allocation.

   It follows that any coalition, which survives all the restrictions imposed, by all the coalitions is a pareto-optimal solution.

9. If such a "grand coalition" exists which is an efficient allocation for all concerned, then we say that a core exists. The core therefore consists of all the undominated allocations.

   A grand coalition is a market in which all buyers and sellers are present. If a grand coalition is the core, then all members choose to be in the market-like many to many relationship rather than forming sub-markets or groups.

10. The core may sometimes have either one allocation or many allocations. It is also possible that there may not be any allocation in the core. This is called an *empty core*. The empty core implies that there is no *stable coalition*. Whatever coalition can be formed, there is always an incentive for some subgroup to benefit by leaving it.

When the core is empty, there is no pareto-optimal situation. In the specific context, it means that members may switch among multiple coalitions opportunistically. Telser (1987) uses the word "chaos" to describe this situation.

## The Framework of Core Theory

In the last section we set out the basic definitions and a simple theoretical ideas of core theory with example. In this section we attempt to describe the basic framework of core theory, which can be used to analyze the organization of economic activity within and across firms. To do this, it is necessary to relate the abstract concepts from the above section to standard notions of competition.

Telser (1987) applies the above concepts to market organization. The framework uses two basic constructs: the *status of contracting* and the *status of the core*. Contracting can be either restricted or unrestricted. If contracting is unrestricted, it means that economic agents (buyers and sellers) are free to form any coalition without any outside interference. There are occasions, however, when contracting is restricted. The restrictions can take the form of limits on the terms of the contract and may also specify who may enter into a contract. In other words contracting is not totally free and open to all. For example, pure competition is an example of unrestricted contracting while monopoly, cartel etc. can be viewed as restricted contracting.

The core can be either empty or non-empty. We say core exits if there is an undominated allocation. If there is no undominated allocation, the core is empty - this means that there is no single allocation, which is acceptable to all members and any coalition of the members. The implication of an empty core is that the market leads to a potential loss to many of its members.

Telser's (1987) primary contribution is to identify that sometimes, the core may not exist. Prior to Telser (1987), the idea that a core may not exist was not considered a possibility. Since most research followed the standard notions of competition without the idea of empty core, many of the arguments made with respect to the degree of competition would also ignore the possibility of the core being empty. For example, under standard theory, one would argue that unrestricted contracting would lead to a more competitive and efficient market. Under the core theory, it would be contingent on the existence of the core.

The two types of contracting and the two states of the core then give rise to four possible situations summarized by the Figures 1 and 2 below. Standard forms of market organization always assume that a core exists so that only the first row is considered.

**Figure 1: The Framework**

| | **Type of Contracting** | |
|---|---|---|
| | **Unrestricted** | **Restricted** |
| **Core Exists** | **Competitive/Efficient Equilibrium**<br>Perfectly competitive equilibrium | **Inefficient Equilibrium**<br>Monopoly<br>Oligopoly<br>Cartels |

| | | |
|---|---|---|
| **Empty Core** | **No Equilibrium** | **Equilibrium**<br>Any solution is efficient, because a perfectly competitive solution is not possible. |

### *Cell 1: Core exists – Unrestricted contracting*

A core is not empty if there is a feasible set of allocations acceptable to all participants and all coalitions of participants. A nonempty core, according to Telser (1987), combines the "optimal mixture of cooperation and competition". The cooperation implicit in a nonempty core is "self-enforcing because no one can gain by rejecting the return received as a member of the grand coalition". The first cell also requires unrestricted contracting so that any member can form a relationship with any other member, with no external compulsions. The first cell is consistent with the standard notion of competitive equilibrium. A competitive equilibrium is efficient in the sense that the total surplus is maximized or, equivalently, there are no deadweight losses. Even though most existing research focuses on this cell, we feel that this should be seen as an ideal or alternately, a limiting case.

### *Cell 2: Core Exists – Restrictions on Contracting*

If the core exists and restrictions are in force, this causes departures from perfect competition and concepts from various theories of imperfect competition become the analytical tools. Examples are monopoly, which is known to cause an inefficient equilibrium. A cartel is another example of restrictions in which firms in an industry jointly set outputs or prices. A noncooperative equilibrium may also fall into this category because, at least in theory, the only legal entities are singletons. This requirement imposes restrictions in the sense that firms cannot form n-member coalitions as they please. The effect of these restrictions is to prevent the market from moving towards a competitive and efficient equilibrium. The question arises as to how these restrictions are sustained. Telser (1987) suggests that a third party could sustain these restrictions. The market alternatives in this cell would be inefficient compared to the perfectly competitive equilibrium when core is nonempty and contracting is unrestricted.

### *Cell 3: Empty Core-Unrestricted Contracting.*

The core may not exist (empty core) for several reasons such as non-convexities, indivisibilities and externalities. Telser (1987) characterizes this as a "chaotic" situation. Observable symptoms of chaos are extreme price-cutting with most firms in the industry losing money, while at the same time buyers want the product and are willing to pay higher prices than those prevailing in the market. For example, soon after deregulation in the airline industry, excessive price wars led firms to make losses, even though consumers were prepared to pay higher prices. Both airlines and consumers were worse off due to excessive competition – airlines lost money and consumers could not find the service at any price. This leads to undesirable outcomes for most of the participants.

### *Cell 4: Empty Core – Restricted Contracting*

When the core is empty, restrictions have to be imposed in order to restore equilibrium. Without such restrictions, there is no equilibrium. A monopoly is a possible restriction, which restricts contracting by limiting the competition to one single firm, or a singleton. A cartel, a set of firms who make decisions jointly is also a restriction, because it reduced the number of possible coalitions. Likewise, vertical integration (buyers take over sellers or vice-versa) imposes restrictions on coalition formation. Long-term contracts, price discrimination practices and deferred rebates (e.g. frequent flyer miles) are also restrictions on the number of possible coalitions.

**Figure 2: Impact of Competition on Contracting**

| | **Unrestricted** | | **Restricted** |
|---|---|---|---|
| **Core Exists** | **Competitive/Efficient Equilibrium**<br>Perfectly competitive equilibrium (guaranteed when N is large) | Industries which become more competitive/efficient due to unrestricted contracting | **Imperfect Competition**<br>Monopoly<br>Oligopoly<br>Cartels |
| **Empty Core** | **No Equilibrium**<br>Chaos | **Industries which become chaotic due to unrestricted contracting** | **Efficient/Inefficient Equilibrium** |

### Symptoms and Conditions for Empty Core

The symptoms of empty core are described by Telser (1987) using the word "Chaos". According to Telser, there is chaos when "price cutting is extreme, most firms in the industry are losing money, and yet it is plain that buyers want the product and are willing to pay higher prices than those currently prevailing."

Telser (1987) identifies some conditions under which the core can be empty. For private goods, which are continuously divisible, there is an "implication" of an empty core if and only if there are constant or increasing returns to scale. For industries with U-shaped average costs (called Viner industries), core may generally be empty. Sjostrom (1989) suggests that avoidable costs could lead to an empty core. Pirrong (1992) suggests large avoidable costs as well as finely divisible demand as possible causes for an empty core. Specifically, he states "core is frequently empty when demand is finely divisible but production costs are not". On the other hand, when the number of traders is large, a core will almost always exist. The core theory is, therefore, appropriate for markets involving few traders and one or more of the conditions discussed above. Explicit modeling is usually necessary to identify an empty core. Figure 3 contains a graphical representation of the arguments.

The above discussions highlight that the unrestricted ability to contract and re-contract among buyers and sellers within an industry is a necessary condition for an empty core to exist. It is this unrestricted ability to contract that allows prices to be bid down to non-profitable levels. Further these discussions imply the necessity of excess capacity. To the extent that one or more producers have excess operating capacity, attracting additional customers by lowering price, provided such price is above marginal cost, creates additional operating profit (or reduces operating loss) for the individual producer. However, the game theory aspect of the empty core dictates that as customers move away from a producer in pursuit of a lower price, that producer itself will react by lowering its price. This process continues to repeat and may result in an empty core. Restrictions on the ability to contract short-circuit this process. The stronger, more permanent the restrictions, the less likely the core is to be empty. Sjostrom (1989) and Pirrong (1992) have applied core theory to the shipping industry. Coyle (2000) uses core theory to explain the electric power generation industry in a deregulated environment. . Nyshadham and Raghavan (2001) offer core theory as an alternative explanation to Daamsgard (1999) explanation as to why an electronic market did not form in the air cargo market in Hong Kong.

Sjostrom (1989) looks to the imposition of artificial restrictions in differing circumstances in order to distinguish between rent seeking behavior and empty core resolution.

Pirrong (1992) suggests the requirement of variable demand for the core to be empty since "it is usually cost minimizing to build several plants and periodically idle one or several in response to changes in demand," and "it may be optimal to operate some of the active plants below capacity". Sjostrom (1989) recognizes variable demand as contributing to the potential of an empty core. However, he addresses the variability of demand in the context of discontinuities in the supply curve. In effect, the greater the variability of demand, the more likely it is for demand to enter a discontinuous region. Sjostrom also recognizes that variability in cost can have the same effect by shifting the supply curve and causing demand to again fall into a region of discontinuity. Further, Sjostrom also recognizes that an industry slump can be sufficient to result in an empty core. While this may be consistent with Pirrong's requirement for demand variability, Sjostrom suggests that such a slump may also result from increased costs. Thus, the important feature is the effect of excess capacity, not necessarily the cause of that excess capacity.

Sjostrom addresses a discontinuous supply function in the context of differing cost structures between firms and the incurrence of sunk costs for individual firms. Sjostrom theorizes that with greater differentials in cost structures the less discontinuous the supply curve. Thus, the more similar the cost function of individual firms, the more likely an empty core is to exist. As capacity of existing facilities is reached, new firms enter only if demand increases sufficiently to justify incurring sunk costs at entry. Thus, the incurrence of sunk costs to create additional capacity creates discontinuities in the supply function.

The most recognized sufficient cause of a discontinuous supply curve is the existence of avoidable costs. That is, once operating capacity has been created (sunk costs incurred), its actual operation may require the incurrence of large avoidable costs, regardless of the level of capacity utilization. A resulting U-shaped cost curve creates a supply discontinuity at a price

equal to minimum average cost due to indifference to produce at this point (Sjostrom, 1989). The greater the avoidable cost, the greater the discontinuity.

A further condition implied by the discontinuous supply curve relates to the size of firm capacity to the market in general. The greater the size of individual capacity relative to the market, the more likely the core will be empty (Sjostrom, 1989). Pirrong (1992), on the other hand, addresses the scale issue from the demand perspective. The more finely divisible demand, the more likely an empty core is to exist. Pirrong views this resulting from increased competitive options. Viewed from the context of the discontinuous supply curve, indivisible demand reduces the likelihood that demand would fall within a discontinuous region of the supply curve.

The discontinuous supply curve indicates that demand elasticity impacts the status of the core. Perfectly elastic demand results in a horizontal demand curve, eliminating the potential for demand to fall within a discontinuous region of the supply function_(Sjostrom, 1989). As a result, the market accepts any quantity that can be supplied at the given price. As a result, competitive pricing reactions are not necessary to fill capacity.

The U.S. airline industry substantially satisfies all of the various conditions, both necessary and sufficient, consistent with the formation of an empty core. The operation of a scheduled airline is in a sense similar to the ocean liner industry described by Pirrong (1992). Just as an ocean liner, an airline at least in the short run, has sizeable fixed avoidable cost. While the large investment in a commercial aircraft represents a sunk cost, its operation includes significant avoidable costs including fuel, labor and maintenance costs. Once however, the airline has committed to a particular fleet and schedule it cannot change output without incurring substantial adjustment cost.

On the supply side the cost conditions of an airline are such that cost per mile flown falls as the number of miles flown increases. However, technological constraints imply that, distance flown can be increased only by reducing aircraft capacity. Further, cost per passenger falls as the number of seats filled on an aircraft raises up to full capacity. Taken together this implies that marginal cost starts increasing well before the payload at maximum range is reached.

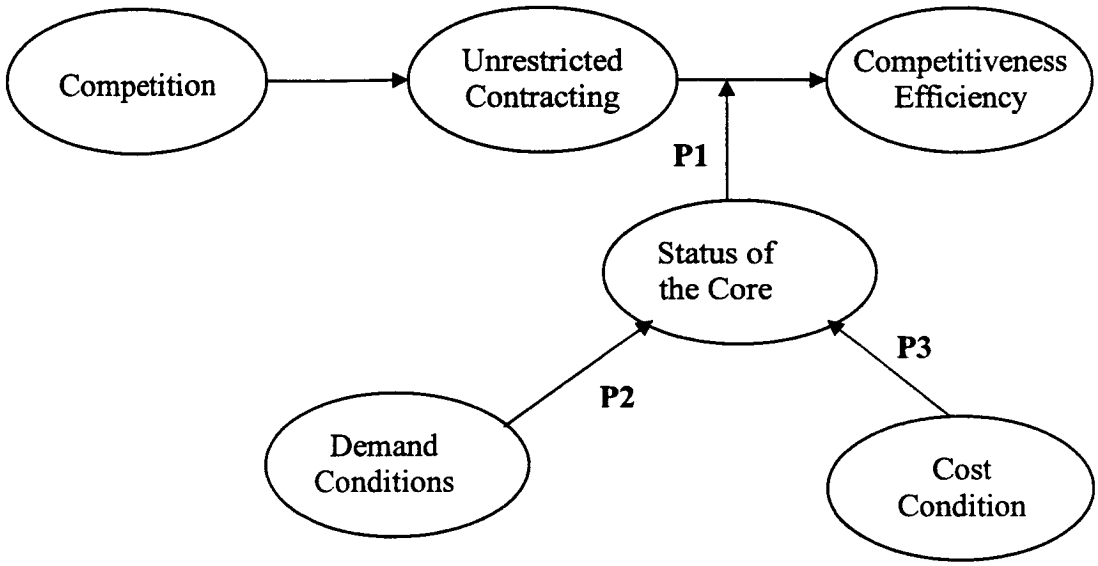
The airline industry has generally operated with excess productive capacity. Further airlines tend to cut prices to short-run marginal cost in the face of excess capacity that will occur due to variations in demand which pushes prices below that required to operate an efficient set of schedules. Recently significant capacity has been idled (parked in the desert) by the industry. This is exacerbated by the existence of the hub and spoke which magnifies these adjustment cost. (see Antoniou (1998)).

On the demand side an airline faces seasonal and cyclical demand. In addition, short-term shocks brought about by events like 911, for example, further increases the volatility in demand.

Thus matching capacity to demand in the airline industry moves it towards an empty core or an unstable equilibrium. Under these conditions imposing competition on this industry will only

make the situation worse. The next section looks at how the participants in the industry have come up with noncompetitive solutions to overcome the empty core problem.

**Figure 3: The Theoretical Model**




We summarize the theoretical model in a proposition form.

**P1:** Unrestricted contracting among agents can have different effects on efficiency depending on whether or not a core exists

**P1.1.** (Core Exists) When Core exists, competition leads to high efficiency.

**P1.2.** (Core does not Exist) When the Core does not exist, competition leads to lower efficiency

Whether or not a Core exists depends on demand and cost conditions

**P2:** If an industry has a finely divisible demand, then the core may not exist.

**P3:** If an industry has large, avoidable costs then core may not exist.

## Resolving the Empty Core: The Case of the Airline Industry

An important contribution of Core theory is the means of resolving an empty core. When the core is empty, restrictions on contracting are beneficial and can create an equilibrium. Such an equilibrium may be inefficient compared to a competitive equilibrium, but is an improvement over the chaotic situation that will persist if core is left empty.

Button (1996) differentiates the conditions where collusion or the adoption of cartel-like characteristics by an industry occurs as a result of rent-seeking behavior (i.e. decreasing market efficiency) or resolution of the empty core (i.e. increasing market efficiency and stability). The notable differences lie in the elasticity of demand, volatility of supply/demand, and barriers to entry. Industries with legal barriers to entry and a smaller number of participants have a higher tendency toward collusion for rent seeking purposes. Industries which have more inelastic demand, variable supply/demand, and a smaller number of participants are more likely to have an empty core, in which case they tend toward collusion in order to resolve the empty core, particularly during recessionary periods.

Many methods exist to resolve the empty core through the implementation of restrictions on contracting. We will discuss some attempts in the airline industry to resolve the empty core problem.

### *Monopoly/Cartel Formation*

First, the U.S. airline industry has adopted certain characteristics similar to cartels. An interesting practice among US Airlines is for them to share fare information with one another on a nearly real time basis through an intermediary called ATPCO (http://www.atpco.net/index2.htm). The ability of US airlines to respond rapidly to fare cuts by competitors comes from the data provided in the ATPCO system. Membership in ATPCO is voluntary but interestingly, most airlines choose to become members of ATPCO and post their fares regularly to ATPCO. ATPCO states that they collect fare information from over 550 airlines and distribute it to global distribution systems (GDS) such as Sabre, Amadeus/System One, Galileo and Worldspan. ATPCO believes that it "creates efficiencies in this process by permitting each airline to submit its information via ATPCO, thereby giving each CRS/GDS the opportunity for a single source of fare related data." This practice of sellers signaling their pricing intentions is somewhat unusual and it may be construed as an uncompetitive practice with intent to collude. To the extent that ATPCO is a voluntary body, airlines would not have joined the organization unless they thought they were better off. In the context of the core theory, this is an attempt by the airline industry to address the problem of empty core.

More recently, the industry has moved toward more direct cooperation amongst competitors through the implementation of code-sharing agreements that allow airlines to coordinate schedules and capacity. The U.S. Department of Transportation has approved such an agreement between United Airlines and US Airways (October, 2002), and Delta, Northwest and Continental are pursuing a similar agreement. These agreements potentially allow individual airlines to coordinate schedules and capacity, and adopt characteristics of cartels further reducing competitive practices within the industry.

### *Price Discrimination*

The U.S. airline industry relies heavily on a sophisticated form of price discrimination called revenue management. Revenue management systems allow airlines to use historical data on load factors on a flight as well as real time load factors to adjust prices for different classes of fares.

This results in different customers paying different prices based on the time and even the channel of purchase, apart from the fare class. While many observers would disagree with the practice of an airline seat being sold at widely different prices, many researchers argue that airlines cannot be profitable unless they do so. It is also argued that, if price discrimination was banned and airlines were forced to offer the same price, many airlines might suffer losses and some might even stop flying. If this is true, this may have a contrary effect of making consumers, who could have paid higher prices, worse off. This is another example of how noncompetitive practices like price discrimination can lead to an efficient equilibrium.

### *Long-term Contracts/Deferred Rebates*

Virtually every major US airline has implemented a frequent flyer program. These programs are designed to increase customer loyalty and effectively increase the cost of "re-contracting". Accordingly, these frequent flyer programs function as a long-term contract between the airline and the individual consumer, which contract provides a deferred rebate in the form of free flights, upgrades to first class, and enhanced levels of service. The benefits of these programs improve with increased purchasing and protect the airlines most valuable customers, the frequent traveling business passengers who typically pay a much higher fare under the revenue management systems.

Instances such as these lead us to look at the notion of 'efficiency' from a broader perspective. Under the broader perspective, maximizing the total surplus (producer plus consumer surplus) may lead to higher efficiency and lower deadweight loss to the society. Under some conditions, non-competitive market structures and practices such as monopolies, cartels, restrictions on transactions among industry members, deferred rebates, price-discrimination etc. may have an efficiency-enhancing role.

## Conclusion and Policy Implication

In this paper we use core theory to examine the airline industry. Core theory helps explain why, for industries with certain cost and demand conditions, a competitive equilibrium may not exist. In such cases, a pareto-optimal outcome for all members does not exist, resulting in an empty core. Unrestricted contracting, enabled by enforcing competition in industries like the airline industry creates more "chaos" when the core is empty.

Some financial economist have questioned the need for government aided competition and have raised concerns about the lax bankruptcy laws (see Wruck, K.H. (1990)) which have enabled inefficient firms to survive in the industry in an effort to promote and preserve competition. The Economist (2002) predicts that due to the protection afforded to it by the bankruptcy laws, U.S Air and United airlines can push through changes like lower fares and wages easily. This will have the effect of lowering prices through out the industry as other airlines try to preserve their market share, pushing the entire industry towards an unstable equilibrium.

McWilliams, A. (1990), argues that current antitrust laws have to recognize that some industries are subject to the empty core problem or an unstable equilibrium. If antitrust laws do not recognize the empty core problem it can lead to business practices as prevalent in the airline industry today, which are inconsistent with our common sense notion of competition. Practices like monopolies, cartels, price discrimination, which are considered inefficient allocation of resources in many other industries it seems can actually be beneficial in the case of the airline industry in bringing about an efficient equilibrium.

Thus government "bail out" of the industry, lax bankruptcy laws and stricter antitrust legislation to aid competition can be potentially damaging to the industry. Surprisingly enough, to solve the problem (i.e., resolve the empty core), the theory suggests that additional restrictions may be placed. The resulting equilibrium is often more efficient compared to the alternative outcome of an empty core which results from unrestricted contracting.

This is a preliminary investigation of the existence of empty core problem in the airline industry. The next step would be to develop a model and test the ideas of core theory for the U.S. airline Industry.

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# An Air Cargo Transshipment Route Choice Analysis

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**Abstract**

Using a unique feature of air cargo transshipment data in the Northeast Asian region, this paper identifies the critical factors that determine the transshipment route choice. Taking advantage of the variations in the transport characteristics in each origin-destination airports pair, the paper uses a discrete choice model to describe the transshipping route choice decision made by an agent (i.e., freight forwarder, consolidator, and large shipper). The analysis incorporates two major factors, monetary cost (such as line-haul cost and landing fee) and time cost (i.e., aircraft turnaround time, including loading and unloading time, custom clearance time, and expected scheduled delay), along with other controls. The estimation method considers the presence of unobserved attributes, and corrects for resulting endogeneity by use of appropriate instrumental variables. Estimation results find that transshipment volumes are more sensitive to time cost, and that the reduction in aircraft turnaround time by 1 hour would be worth the increase in airport charges by more than $1000. Simulation exercises measures the impacts of alternative policy scenarios for a Korean airport, which has recently declared their intention to be a future regional hub in the Northeast Asian region. The results suggest that reducing aircraft turnaround time at the airport be an effective strategy, rather than subsidizing to reduce airport charges.

# An Air Cargo Transshipment Route Choice Analysis

## 1. Introduction

Asian countries experienced the strongest growth in the international air cargo business after the recovery of the recent financial crisis. In 1999, the Asian region enjoyed export volume rising by 30.3 per cent, and cargo revenues by 45.2 per cent. The Republic of Korea saw particularly strong growth in export volumes and yields, and the region's two main airports - Hong Kong and Tokyo - were the second and third busiest freight handlers in the world. This trend is likely to sustain as China's economy consistently grows with their entry to the WTO, despite of global economic slowdown, and the influential Japanese economy spiraling downward.

Due to the surge in demand, along with the freer international aviation market in the Northeast Asian (hereafter NEA) region, the NEA countries start contemplating on aggressive competition to attract new airfreight carriers. Their efforts are reflected by the current and future expansion plans released by those countries. China has announced that they will expand PuDong airport to 5 million tonnages from the current capacity of 0.75 million within the next two decades. The capacity of Japan's Kansai airport is planned to increase more than double. Korea also has made considerable investments: They have constructed a new international airport at Incheon, and two seaports at Busan and Kwangyang.

There is an important implication for a country to become a global or regional transport hub. History on the evolution of cities such as Rotterdam and Hong Kong witnesses that a positive feedback link exists between the activity of multinational corporations (MNC's) and the success as a transport hub in the recipient country. A transport hub attracts MNCs to concentrate their logistics and distribution functions in the country. Such high value added activities increase not only their employment, and their domestic income, but also traffic volumes passing through the hub airport. At the same time, the increase in the transport volume at the airport reinforces the incentives of other MNCs to locate their logistic centers in that country. Those countries that intend to develop hubs hence face a "chicken and egg" problem: Whether to entice MNCs first by creating an incentive scheme, or to increase the transport volume first to become a hub, and then attract MNCs. While several existing studies investigate determinants of MNCs location choice (surveyed in, for example, Caves, 1996; Oum and Park, 2002), a severe lack of empirical studies on this topic remains.

The purpose of this paper is to offer the first empirical study to analyze the determinants of international air cargo traffic flows with an application to the NEA region. Obviously whenever a direct shipping route is available, holding a line-haul rate fixed, a freight forwarder prefers to choose direct rather than transshipment. In order to analyze the

tradeoff between values of time and money from the eyes of freight forwarders, consolidators, or large shippers, we solely focus on the transshipment route choice in the analysis. This limited scope of our analysis, however, does not bias estimation results, because the majority of origin-destination (hereafter O-D) shipment volumes go through a transshipment port in the NEA region. A unique feature of our air freight transshipment data in the NEA region in the year of 2000 provides us with an interesting experiment as to the identification of critical factors determining the freight flows. The data contain aggregated air cargo transshipment volumes originating from and destined for the NEA area, along with airport characteristics and airfreight fares. The paper uses a discrete choice model of an agent (i.e., a freight forwarder, a consolidator, or a large shipper) who makes a routing choice, and identifies critical determinants of transshipment freight flows. The analysis incorporates two major factors, monetary cost (such as line-haul cost and landing fee) and time cost (i.e., aircraft turnaround time, including loading and unloading time, custom clearance time, and expected scheduled delay), along with some other controls. The estimation method considers the presence of unobserved attributes, and corrects for the resulting endogeneity by use of appropriate instrumental variables. The paper finds that transshipment volumes are rather sensitive to the time cost than monetary cost: The reduction in the aircraft turnaround time by one hour would be worth the increase in the airport charges by more than $1000. This finding implies that it would be more effective to promote airports by reducing aircraft and air cargo turnaround time, rather than reducing airport user charges.

Using the estimation model and results, the paper conducts simulation exercises to measure the effect of airport's price and non-price policies on the transshipment volumes. The paper focuses on Korea in particular to investigate the impact of their counterfactual policy changes. Two policy alternatives are considered, one for airport charges, and the other for aircraft turnaround time. The simulation exercises find that, a landing fee would have to be cut half in order for Seoul to increase its share by 20%, while the 30% improvement of the aircraft turnaround time would do the same job. This finding suggests important policy implications to airport authorities or local governments: Investing money for reducing turnaround time at an airport is an effective strategy, rather than subsidizing the airport to cut user charges. When capital is in short supply for investment, it may make sense to raise airport charges, and then to use their operating profits for capacity expansion and automation including electronic data interchange (hereafter EDI) system.

A growing body of theoretical work finds the causal relationship between MNC location patterns and transport network structure. Two major strands in the literature reflect the nature of the chicken-egg problem discussed above. One strand is to examine the designs of transport networks when the economies of density exist. Hendricks, Piccione, and Tan (1995) find that the economies of density often lead to hub-and-spoke networks. Oum, Zhang, and Zhang (1995) find that the hub-and-spoke system may be used as entry deterrence, while Berechman and Shy (1996) show that it can also accommodate entry if the passenger's time value and aircraft capacity constraints are taken into account. The other strand focuses on how industrial location patterns emerge under the given structure of transportation networks. The work includes Krugman (1993), Konishi (2000), and

Fujita and Mori (1996). Mori and Nishikimi (2002) analyze the interaction between the two forces. The paper makes a contribution to the empirical side mostly concerned with the first group of the literature.

The paper is organized as follows: Section 2 describes air freight business. This section also introduces a data set and important explanatory variables. A discrete choice model discussed in Section 3 uncovers determinants of the transshipment volumes originating from and destined for the NEA region. Section 4 presents estimation results. Section 5 conducts simulation exercises focusing on a Korean airport. Section 6 concludes the paper's findings.

## 2. Air Freight Business

This section describes the international airfreight business surrounding the NEA region, and introduces major variables that likely influence the air cargo transshipment activities. Many of the discussions on institutional features of air freight business are taken from Rigas Doganis (2002).

The logistics of moving freight is more complicated than that of moving passengers. It involves packaging, preparing documentation, arranging insurance, collecting freight from the shipper, facilitating customs clearance at origin and destination, and completing final delivery. This complexity of the job has encouraged the growth of specialist firms that carry out these tasks on behalf of the shipper and provide an interface between shippers and airlines. In this paper, we consider freight forwarders, consolidators, or large shippers as decision makers with respects to air cargo routing choice. For simplicity, we refer these three agents altogether as "freight forwarders," unless the use of this term creates confusion.

Air freight business is inherently competitive. This is because most freight, except for emergency freight, is indifferent to the routings made to move from its origin to its destination. A shipper is not concerned whether a shipment goes from New York to Kuala Lumpur via Tokyo, Shanghai, or Hong Kong with several hours of transshipment at one of those airports, provided that the shipment arrives at Kuala Lumpur within the expected time. Few passengers would put up with such a journey. Thus, in most cases, a freight forwarder can use numerous routings and airlines to get its destination. The flexibility in routing choices ensures inter-airport as well as inter-airline competition that is absent for passengers on the same route.

Airfreight transshipment is a very important aspect of the air cargo industry in the NEA region. Figure 1 shows direct and transshipment shares of air cargos delivered between North America and the NEA countries in the year of 2000. Roughly 70 % of airfreight reaches final destinations via one or more transshipment points. Anchorage has the highest share of transshipment air cargoes originating from the North America, because many U.S. airlines use short- or middle-haul aircrafts to collect their freight to

consolidate at Anchorage, and then use long-haul aircrafts to deliver to the NEA region. Tokyo takes half of the transshipping shares when freight is shipped from the NEA. Figure 2 presents the share data between Europe and the NEA area. A high share of 60 % of the cargo traffic from the NEA region and Europe is transshipped on the way to the destination. Again the table shows that Tokyo plays a dominant role in the freight transshipment.

We focus on the air cargo movement between origin and destination gateway airports, rather than their real origin and destination points, primarily because our data do not contain the record on where the shipment comes to and goes from gateway airports. Table 1 lists major airports and their main characteristics related to the airfreight traffic in the NEA region. By limiting our analysis on the air cargo movement between gateway airports only, we implicitly assume that there is no alternative routing choice that involves inter-modal movement[1]. This should not impose any serious problem, however, as such inter-modal movements are rather limited in airfreight transport.

Table 1 lists the airports under our study in descending order of landing fees for Boeing 747-400 with the gross takeoff weight of 395 tones. A casual observation on the landing fees informs us that the U.S. airports tend to have lower landing fees than the Asian airports. Japanese airports have the highest landing charges: Narita airport charges USD 9,700, roughly 19 times higher than Atlanta that has the lowest charges in our sample.

The number of runways ranges from 1 at Kansai to 6 at Chicago O'Hare, and all the airports in our sample are able to accommodate B 747-400 as indicated by the length of runways[2]. Anchorage has the largest cargo handling capacity, whereas Beijing has the smallest cargo handling capacity, though significant capacity expansion is expected over the next two decades. Singapore has by far the largest cargo terminal space. The variables in the last two columns, throughput and average hours for loading/unloading and customs clearance, are detailed later in this section.

Conditioned on the choice of transshipment, freight forwarders must consider several cost factors to decide which airport to stop over in order for them to minimize the total shipping cost. The cost factors are roughly grouped into two categories: monetary cost and time cost. Monetary cost is equivalent to the sum of airport charge and freight line-haul rate. Line-haul rate is aircraft operation cost, and depends on the distance of each route, and the number of required transshipment. In many cases, transshipment is made only once, and our data contains only such case.

Time cost comprises following four factors: cruising time (which must be highly correlated with the route distance), loading and unloading time, and customs clearance and other processing time.

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[1] Inter-modal movement refers to the use of more than mode of transport. For example, for shipments from New York to Kuala Lumpur, some shippers may transport by air via Hong Kong, whereas others might fly their shipments to Singapore first, and then truck to Kuala Lumpur.

[2] B747-400 requires runways with a minimum length of 2800 meters.

The next three subsections examine each of the factors in detail. Section 2.1 describes monetary costs, and Section 2.2 time costs. Section 2.3 discusses other possible unobserved factors that may influence the freight forwarders transshipment route choice.

## 2.1. Monetary Costs

This subsection discusses two main components of the monetary costs: (A) line-haul rate and (B) airport charges.

**A. Line-haul rate**:

The data on line-haul rates used in this paper are the list price by route published by IATA (the International Air Transport Association), TACT book 2001. Price is a key element of airline services. The actual transaction fares are sometimes discounted from the list fares, especially for large freight forwarders, and the extent of discount reflects the degree of bargaining power. The actual transaction fares are made confidential, and it is very difficult for researchers to obtain such data. Thus we use the listed line-haul rates in the estimation.

The distribution of all the line-haul rates in the data set is presented in Figure 3. There is a clear trend that the line-haul rates increase with distance. The unit-distance rate indicates economies of scale with distance, indicating the presence of fixed cost. Notice that short-haul shipping is within the Asia region, the medium-haul is mostly the shipment to and from the U.S., and the longest is with Europe.

**B. Airport Charges**:

Another significant element of freight costs is landing fee. Freight forwarders have to pay a share of landing fee based on the weight of their airfreight. While airlines have tried to hold down the increase in landing fees in particular countries acting through IATA, an individual airline has little scope for negotiating better rates for itself.

Airport charges are shown in Table 1, and were briefly discussed earlier in this section. Many Asian airlines have relied heavily on cargo revenue, and dedicated cargo carriers do not play a big role in Asia, unlike those in the United States. For instance, EVA generates 39.4% of its revenue from the cargo business, and Cathay Airline generates 26.4%, while the United Airlines generates only 5.2% from air cargo. Though several airlines, such as Korean Air and China Air own dedicated cargo aircrafts, much of airfreight is still carried in the belly of passenger aircraft.

The level of airport charge depends partly on the costs at the airport and partly on whether the airport or the government is trying fully to recover those costs or even make a profit. As a result, airport charges (landing fees) vary enormously across different

airports. The highest landing fee is charged at $USD 9,700 by Narita International airport, Tokyo, and the lowest is at $USD 512 by Anchorage. Because of the limited data availability of landing fees, we use the B747-400 landing fee as a representative airport charge. The use of the landing fee data is not completely satisfactory in that they are not able to capture the differences in the load factor. If these missing variables are roughly correlated with the airport size, then we could use a random coefficient model introduced by Brownstone and Train (1999). Their method allows us to interact the landing fee with the airport size with an explicit distributional assumption on freight forwarders' heterogeneity. Though the application of this method is beyond the scope of this paper, it would be an interesting extension for future research.

## 2.2. Time Costs

This subsection lists three important elements of the time costs: (A) cruising time, (B) loading/unloading and customs clearance time, and (C) the time cost caused by scheduled delay.

**A. Cruising Time**

As easily expected, cruising time is closely determined by the route distance. Thus, the variable, line-haul rate, takes care of the cruising time in the estimation.

**B. Loading and Unloading (L/UL) Time, and Customs Clearance Time**

In many countries, aircrafts have to go through the customs, even though the cargoes just pass through a transshipping port. They also spend time to load and unload their cargos at the airport. A freight forwarder has to consider these time costs upon its choice of a transshipment route. If the average customs clearance time takes too long at some airport, a freight forwarder is likely to avoid the route given the other features of the airports. The data on the sum of U/UL time and customs clearance time are presented in Table 1. It appears that the sum of these time costs does not vary across the airports.

**C. Scheduled Delay** [3]

The air cargo service is enhanced by more frequent departures and greater likelihood of the reloaded cargos on preferred flights. The data contain the numbers of air passenger trips per week by airport for both incoming and outgoing flights by route. We use the idea of Douglas and Miller (1974), and calculate the expected scheduled delay as the inverse of the frequency. The expected schedule delays in arrival and departure are different across city pairs. We calculate the expected maximum hours of scheduled delay by taking a sum of scheduled delays on arrival and departure.

[3] Though UPS and Fedex started operating at Incheon airport in Korea, charter flights are not yet popular in the NEA region. Thus we solely focus on scheduled flights in this paper.

Freight forwarders would shy away from choosing the airport with longer expected scheduled delay, holding the attributes of the other airports constant. The scheduled delay indicates how many hours on average an air cargo has to wait at the airport before catching the next flight. During the waiting period, the freight has to be reloaded, and clear the customs. For some route, the customs clearance takes so long that the freight has to stay more than the minimum expected scheduled delay time. If this is the case, the freight has to be held at the airport until the next available scheduled flight. Therefore, we calculate the expected total time cost at a particular airport *j* as follows:

$(n_{ij}+1)$*(expected scheduled delay)$_{ij}$ > (L/UL time + custom clearance time)$_j$ > $n_{ij}$*(expected scheduled delay)$_{ij}$

where $n_{ij}$ is the number of scheduled flights that have to be missed for route *i* at airport *j* in order for the airfreight to complete being reloaded and processing customs clearance. The first term of the above equation, $(n_{ij}+1)$*(expected scheduled delay)$_{ij}$, is defined as the time cost, the length of time that the aircraft has to stay at airport *j* on route *i*. The data on frequency are by O-D ports pair. The time cost is obtained as the expected maximum hours of stay at the airport, that is, the sum of the scheduled delays of two routes, one with the origin, and the other with the destination. The summary statistics of this variable are in Table 2.

## 2.3. Throughputs

Throughput is the total volume of traffic processed through an airport. This is an important determinant in explaining the transshipment route choice in two ways. First, the import volume increases with the size of hinterland demand, and thereby more aircrafts stop over and drop off freight that meets the demand. Secondly, the throughput size serves as a good indicator of the attractiveness of the country in the eyes of MNCs who are looking for new subsidiary locations. The literature on economic geography (surveyed in, for example, Fujita, Krugman, and Venables, 2000) finds the agglomeration effects of MNC's location choice. We use the amount of throughput as a proxy for the size of hinterland demand. Table 1 shows the throughput data by airport in the year of 2000. High throughputs in Hong Kong and Anchorage are mostly due to freight transshipment, and that in Tokyo may be due to the size of domestic demand.

## 2.4. Casual Observations across Variables

This subsection provides simple correlations between the transshipment volumes and critical explanatory variables. Section 4 formally estimates such relationships with a discrete choice model.

We select five airports as important transshipment points in the airfreight traffic in the NEA region: Beijing, Bangkok, Osaka, Shanghai, Seoul, and Tokyo. We include Bangkok, because this is a transport hub for airfreight between the north and south Asian regions. Therefore, Bangkok may not be in the same competition as the rest of four airports. Hong Kong has to be excluded from the data, the reason being that no data are available on the airfreight flows with inland China. Since Hong Kong is virtually a gateway port to China, it is not desirable for us to use the Hong Kong data without the data of Chinese cargo freight.

Figure 4 is a scattered diagram indicating the relationship between transshipment shares and landing fees (in unit of USD) for the selected airports. We calculate the transshipment share for a particular airport by first calculating the proportion of the transshipment volume passing through the airport in each pair of origin and destination, and then averaging them over all the combinations of origin and destination. Thus this transshipment measure is based on the sub-population of the O-D freight volume, and does not take into account the direct shipment.

The figure illustrates that, except for Tokyo, there is a negative correlation between landing fee and transshipment share. Tokyo has a high share with high landing fee, making itself distinctively different from other airports.

Figure 5 presents how the transshipment share is related to aircraft turnaround time. The figure reveals, again save for Tokyo, a positive relationship between the share and turnaround time. One might think that this relationship appears odd because longer turnaround time increases the share. The figure, however, should not be interpreted as the causal effect of time. Rather the figure indicates that the turnaround time, or service frequency, may be endogenous: The increase in share would exacerbate congestion, forcing the aircraft turnaround time longer. In the estimation, we carefully control for this endogeneity by using appropriate instrumental variables.

Both Figures 4 and 5 find that Tokyo's Narita airport is very different from other airports: Tokyo has a high share yet with highest landing fee and shortest aircraft turnaround time. Historical reasons place Tokyo as rather an outlier in the figures (Hansen and Kanafani, 1990). The introduction of jets into commercial service and high economic growth in Japan provided Tokyo with the only major Asian destination with the United States in the late 1950s. Tokyo's dominance continued to grow with Japan's strong local market and the liberal fifth freedom rights of U.S. airlines out of Tokyo. The last two decades have witnessed that Tokyo's dominance is slowly changing, but still Tokyo has enjoyed sitting on the laurel from the past. In account of this Tokyo's historical perspective, we create a dummy variable to deal with Tokyo differently from the other airports.

## 2.5. Unobserved Variables

We have discussed two major factors, monetary and time costs, which likely change the relative transshipment shares. Other factors may also likely influence the freight forwarder's route choice. We discuss three such factors in this subsection: congestion, the international aviation regulation, and technology advance in custom administration. Although we do not have data of these three variables, there is a concern with resulting endogeneity problem that presumably bias estimation results. We discuss the source of the endogeneity problem in this subsection, and a correction method in Section 4.2.

(1) Congestion

Congestion likely correlates with scheduled delay, because, an airport becomes crowded with the number of scheduled flights, given the limited capacity of the airport and efficiency of the customs clearance. This congestion factor, since unobservable, would likely remains in the error term obtained from estimation. We therefore concern with a correlation between the error (which is partly reflected by congestion) and the explanatory variable, scheduled delay. In the estimation, we correct for this possible endogeneity as discussed in Section 4.

(2) Bilateral Air Services Agreements and Inter-airline agreements

Over the years, each country has signed a series of bilateral air services agreements with other countries aimed at regulating the operation of air transport services. Although a liberal type of bilateral agreement (i.e., the Bermuda type) has become more widespread, as we see in the recent Hong Kong's experience, the agreement sometimes does not preclude airline pooling agreements, which effectively restrict capacity competition. Nor do they preclude subsequent capacity restrictions imposed arbitrarily by governments to prevent foreign carriers from introducing a new aircraft type or to limit increases in frequencies (See Cheung, et. al, 2002, for the recent case in China). Many features of a state involvement in aviation are not clearly observable.

Bilateral air services agreements and inter-airline agreements influence the airline frequencies to be operated. In countries where more than one national carrier operates international services, the country's own licensing or regulatory controls may influence the sectors on which their airlines operate. Since we do not have an appropriate measure of this state involvement in aviation, these aspects of regulation may be captured by the unobserved variable, $\xi$. Therefore, there is a concern for possible endogeneity in that the expected scheduled delay (calculated from the frequency data), and the error may be correlated one another. We discuss a set of instruments to correct this endogeneity problem in Section 3.2.

(3) Advance in Customs Administration

Historically, revenue raising was a major function of customs administration. Importance of this role diminishes as tariff barriers are reduced. Instead, customs administration plays an important role in attracting international airfreight. Unpredictable delay in customs clearance, or unexplained changes in the classification of goods disrupt efficient logistic flows, and thus hinder the hub development in air cargo transshipment. The technology, such as EDI system, makes the customs procedure simplify by computerizing the shipment information, and makes it efficient by allowing for pre-clearance of the shipment. Some airports, such as Singapore, created a bonded zone area so that the transshipment goods can avoid customs. Though customs clearance in many airports is yet processed manually, some other airports strive to simplify the processes. Unfortunately we do not observe the extent of efficiency achieved by each of the airports regarding customs clearance process. Since the efficiency of customs is often measured by time, the concern might arise on the correlation between the unobserved customs efficiency and the time cost variable. Similarly, if the airlines realize that freight forwarders has a higher willingness to pay for the airports that have efficient customs administration, and there are routes in which such airlines have some degree of market power, they might increase the line-haul fare to raise their revenue. This generates another concern for the endogeneity with the line-haul cost variable. A set of instruments to correct the endogeneity issue is discussed in Section 4.2.

# 3. Estimation Model

This section introduces an estimation model to describe the route choice process made by freight forwarders. The choice model is derived from a random utility discrete choice model of freight forwarders. Since we do not observe the route choice of individual freight forwarders, we aggregate individual forwarders to obtain a behavioral model of transshipment, while still allowing for heterogeneity across the forwarders.

Each freight forwarder, $i$, is assume to maximize the following indirect utility function by choosing the route, $j$, among a set of alternative transshipping routes in a particular origin-destination gate ports pair:

$$u_{ij} = \sum_k X_{jk}\beta_k + \xi_j + \varepsilon_{ij},$$

where $u_{ij}$ is the freight forwarder $i$'s utility from choosing the route $j$ to ship freight from the origin to the destination. The utility can be interpreted as a negative of the transshipping cost. The vector, $X_j$, includes the variables that reflect the freight forwarder's transshipment route choice. A k-the component of this vector is denoted by $J_{oke}$. The previous section discusses that the monetary and time costs are the two most important determinant factors in the route choice. The time cost variable indicates how many hours for which a representative air cargo has to stay at a particular airport. For monetary costs, we use following two measures: line-haul fare, and landing fees. Detailed description of the variables is found in Sections 2.1 and 2.2. We also include as

explanatory variables a size of hinterland demand (i.e., throughput), and the Tokyo dummy interacting with line-haul cost, landing fee, and time cost. As discussed in Section 2.3, the explanatory variables do not cover all the important factors affecting the transshipping routing choices made by freight forwarders. We therefore include an error term, $\xi_j$, to capture such unobserved (to the econometrician) factors with zero mean. The other error term, $\varepsilon_{ij}$, determines the slope of the transshipping route demand curve. We impose the assumption on $\varepsilon_{ij}$ that generates a standard logit structure. In order to obtain consistent estimates of the parameters, $\beta$, our estimation method should take care of the possible endogeneity problem, i.e., the correlation between some explanatory variables and $\xi_j$. We discuss a method for correcting the endogeneity bias in Section 3.2.

## 3.1. The Logit Model

In our analysis, a freight forwarder chooses a transshipment point to maximize its utility (or minimizes its shipping cost). The standard conditional logit model provides a closed form choice probability. The share for route $j$ with in a particular combination of the origin and destination ports is given by:

$$s_j = \frac{\exp\left(\sum_k X_{jk}\beta_k + \xi_j\right)}{\sum_{p\in\Phi_{O-D}} \exp\left(\sum_k X_{pk}\beta_k + \xi_p\right)}.$$

The share of the route $j$ is denoted by $s_j$, and $\Phi_{O\text{-}D}$ is all the transshipping routes in a given pair of the origin and destination airports. A log-transformation yields an aggregate linear regression model for the route $j$ (The previous work, for example, Berry (1994), uses this technique):

$$\ln s_j = \sum_k X_{jk}\beta_k + \xi_j - \log\left(\sum_{p\in\Phi_{O-D}} \exp\left(\sum_k X_{pk}\beta_k + \xi_j\right)\right),$$

where $j\in\Phi_{O\text{-}D}$. Since the inside the log-transformation is highly nonlinear, we look at the within estimates by subtracting two share equations of the routes $j$ and $l$ within the same O-D pair. This procedure removes a common component affecting the routes within the same O-D pair, and, in particular, the third term in the right hand side of the above equation:

(1)

This is our base estimation model. Notice that the constant term is cancelled out in (1). The identification comes from the variations in transshipment characteristics in each combination of airports. We could use the ordinary least squared method (OLS) to estimate this model, however, we are concerned about the possible correlation between some explanatory variables (i.e., $X_{jk} - X_{lk}$) and the unobserved error (i.e., $\xi_{jk} - \xi_{lk}$). The next section explains the sources of this endogeneity, and the method to correct the problem.

## 3.2. Identification

There are concerns for endogeneity in that some explanatory variables in ($X_{jk}$-$X_{lk}$) may be correlated with the difference in the unobserved attributes, ($\xi_{jk}$-$\xi_{lk}$). This section discusses the sources of endogeneity, and a method to correct the problem. One source of the possible endogeneity comes from the missing variables we discussed in Section 2.4. We are concerned about the possible bias from missing three variables: congestion, aviation regulation, and customs efficiency. All these missing variables could correlate with the service frequency, which we used to create a time cost variable. Furthermore, unobserved customs efficiency might also correlate with line-haul fare, through airlines market power: Some airlines may be able to charge a high freight fare with a route with efficient customs procedure, because the route would attract forwarders who concern on shipping time. The correlation of the unobserved attributes with the explanatory variables would generate a biased estimate without the use of appropriate instruments.

In the estimation, we thus use instruments that would correlate with the endogenous variables, but not with the unobserved attributes. We consider two sets of instruments. The first set of instruments used in the estimation is related to airport characteristics: length of the runways (m), and cargo terminal areas ($m^2$). We expect that these instruments control for endogeneity of time costs. The length of the runways indicates what type of aircrafts can land on the airport. Enough runway length is required for B747 to land and take off, and thereby this instrument may correlate with the frequency of particular aircraft types, and therefore time cost. The cargo terminal areas may correlate with U/UL time, though the sign of correlation is ambiguous: If the terminal areas are large relative to the size of throughput volume, there may be economies of scale to making U/UL process shorter, leading to a negative correlation between these two variables. If there are diseconomies of scale, a sign would be positive. Those two variables may likely be exogenous to congestion, aviation regulation, and customs efficiency. Thus they can serve as instruments in our estimation.

The second instrument regarding for the line-haul fare is the route distance. As discussed in Section 3.1, the line-haul cost is highly correlated with the distance. In particular, Figure 3 observes the strong relationship between distance and fare: Longer the distance, the faster the line-haul fare drops by a declining rate. In order to capture this nonlinear relationship between the fare and distance, we include the distance variable up to the second order polynomials in a set of instruments.

In a model with exogenous airport characteristics, the characteristics of other competing airports are also appropriate instruments. With some regional market power by airport, the transshipment volume depends on the relative attractiveness to the other airport characteristics. Holding the characteristics of a particular airport constant, the airport would lose transshipment freight share as a characteristic of other airports improves. The characteristics of other airports are thus related to the service frequency, but since characteristics are assumed to be exogenous, they are valid instruments. In the present study, we include in the set of instruments the sum of characteristics of the other airports in the NEA region. we assume that Anchorage does not face with effective competition from the NEA area.

# 4. Estimation Results

This section examines estimation results of the model (1). The definition of the variables and summary statistics are presented in Table 2. The previous subsection discusses that line-haul rate and turnaround time are likely endogenous in the estimation. Thus we use two-stage least squared method (hereafter 2SLS) in the estimation.

Table 3 shows the estimation result. The table shows two different specifications. The specifications differ in how to deal with the endogeneity in line-haul rate. The specification, (B), treats line-haul rate as an endogenous variable, the other specification, (D), uses a proxy variable, distance, to substitute for the line-haul variable. As we discussed in the Section 2.1, the line-haul cost and distance closely correlate with each other. Since a geographical distance between airports is exogenous, (D) does not require instruments for the line-haul rate. Note that we still need to control for turnaround time. The model (D) is typically called a gravity model, and frequently used for forecasting traffic flows. For each of the specifications, (B) and (D), we provide the results from OLS, for the purpose of comparison ((A) and (C) respectively).

Tokyo's Narita has been a dominant airport since the 1950s with huge hinterland demand. In order to control for this historical element discussed in Section 2.5, we add the Tokyo dummy for the variables of landing fee, turnaround time, and line-haul rate (for the models (A) and (B)), or distance (for the models (C) and (D)). We use instruments specific to Tokyo, in order to control for endogenous variables interacting with this dummy.

Table 3 finds that the model fits are not impressive at the first glance: The model explains only up to 46% of the variation in the dependent variable. Note, however, that the obtained results are within estimators: We obtain the estimators using the variations only among routes given each O-D pair. Provided that some of our data only vary by airport, but not by route, we consider that the results are satisfactory. For the 2SLS estimation, the table also shows averaged first-stage F-statistics for the explanatory power of the instruments, conditional upon the included exogenous variables. The F-statistics indicate that the instruments are not weak. The statistics for over-identifying restrictions (the J-statistics) test the validity of instruments conditional on there being a set of valid instruments that just identify the model. The statistics shown in the table would not generally reject the hypothesis that some of the instruments are orthogonal to the unobserved error term with the 99-percent confidence level.

The comparison of the first two results, (A) and (B), shows that the endogeneity problem appears to be significant in the estimates of line-haul rate and turnaround time. The line-haul rate has a positive coefficient in the OLS result, whereas it is negative (but not significantly different from zero) after controlling for the endogeneity. This result indicates that the line-haul fare may be positively correlated with the variables that we do not observe in the data. We also expect that the turnaround time variable has an upward biased estimate if not appropriately controlled, because, for example, the unobserved congestion effect may be positively correlated with the time variable. The result from the 2SLS confirms our prediction: The turnaround time coefficients are lower in 2SLS by 40%.

The coefficients of the landing fee and throughput variables are both significantly different from zero in (A), but not in (B) even though they have the same signs. The throughput variable shows that after controlling for all the explanatory variables, the transshipment airport exhibits economies of density on average. This interpretation is, however, clouded by the effect of congestion.

The Tokyo dummy estimates indicate the extra effects of those variables relative to the other airports. Tokyo dummies are positive both for line-haul cost and turnaround time. The magnitude of the estimates are high enough that the transshipment share through Tokyo increases with line-haul cost and turnaround time. Some of these odd results are already manifested in the preliminary inspection of the data shown in Figures 4 and 5.

The specifications (C) and (D) estimate the gravity equation. Both estimation results are similar to the previous results that use the line-haul rate as an endogenous variable; however, the standard errors are considerably improved. Though the two 2SLS results are qualitatively the same, the absolute values of the coefficients in landing fee and turnaround time in (D) is larger than those in (B).

The comparison in the magnitudes of the landing fee and time variables show that the monetary cost is not so important a determinant factor as the time cost. The estimation result (B) indicates that, holding the other airport competitors' characteristics, and focusing on airports other than Tokyo, if an airport is able to reduce the aircraft

turnaround time by 1 hour, that effect would be worth the increase of the airport charges by $1361 ($1146 based on the estimates from (D)). This result implies that the time factor would play more effective role in influencing the transshipping volume, rather than the landing fee itself.

In light of the allocation in the airfreight cost, our estimation result makes sense. For the world's airlines as a whole, airport user charges (that is, airport charges and en route facility charges) account for just over 5 percent of their total costs. The proportion generally rises, but by small amount, for international airlines operating relatively short-haul sectors, where landings occur more frequently. For some airlines, such as KLM, the proportion dropped to just below 5 percent, while for US carriers it was generally 2-4 percent.

On the other hand, usually the airfreight business deals with the commodities with high value-added, which would be time sensitive. Most goods being shipped by air have a high value-to-weight ratio. Since cargo rates are generally based on weight, the higher the value of an item in relation to its weight, the smaller will be the transport cost as a proportion of its final market price. This tendency for high-value goods to switch to air transport is reinforced if they are also fragile and liable to damage or loss if subject to excessive handling. The estimation results capture this nature of the time-sensitive airfreight business.

# 5. Simulation Exercises

The previous section estimates what factors determine the freight forwarder's choice of transshipment routes. The estimation results reveal that the aircraft turnaround time plays a rather important role in the route choice made by freight forwarders. The previous section estimated that the reduction in the turnaround time by 1 hour is worth the increase in airport charges by more than $1000.

Based on the estimation results in Table 3, this section examines what alternative policies would be most effective for an airport to increase transshipment volumes. We are particularly interested in Korean airports, since Korea recently declared their intention to become a regional logistic hub in the NEA region. Obviously there are many policy tools for the country to achieve such a goal: designing tax incentives for MNC logistic centers, establishing protection of intellectual property rights, setting transparent regulatory environments, and so forth. This paper considers only two of such policy tools. One is airport charge, including landing fee and airport navigation charge. The other is aircraft turnaround time, due to a reduction in loading and unloading time, simplification of customs clearance procedure, and an increase in flight service frequency. We use the estimates from the specification (D) in the following exercises, however, those from the specification (B) provides a similar result.

Figure 6 shows how the transshipment volume would change with the reduction of airport charges at Seoul airport. We ask the following question in this simulation: How much transshipment volume would increase if the airport user fee were reduced by 10% or 30% from the actual. We calculate the counterfactual transshipment volumes based on the assumptions, and compare them with the actual volume. Partly due to the fact that Seoul airport charges already a lower landing fee, the impacts of airport charges would not be very significant even if the fee were cut by 30%: The increase of the volume is 11.7%, mostly switched from Kansai airport in Osaka. This result makes sense in view of the geographical proximity between the two airports (we takes into account the geographical differences by including the O-D distance variable in the set of instruments).

The counterfactual policy scenarios with respect to aircraft turnaround time are examined in Figure 7. We ask how much transshipment volume would increase if the turnaround time were reduced by 10% (i.e., 14 minutes) and 30% (i.e., 40 minutes) from the actual level. The turnaround time in Korea averaged over routes was 2.25 hours. As expected from the estimation results in the previous section, the impacts of this alternative policy would be significantly large: The volume of transshipment through the airport increased by 18.3% if the turnaround time should be shortened by 40 minutes.

The simulation results illustrate that a slight reduction of turnaround time would have a great deal of impact on the transshipment volume for airport. A policy of reducing airport charges may not be a most efficient strategy to attract more airfreight volumes from other Northeast Asian airports.

The Northeast Asian region experienced the strong growth in the international air cargo business after the recovery of the recent financial crisis. Due to this surge in demand, along with the freer international aviation market, the countries in the Northeast Asian region have started contemplating on aggressive competition to create hub airports.

With the use of the unique feature of the air cargo transshipment data in the Northeast Asian region, this paper identified the factors essential to become a transport hub airport. The paper used a discrete choice model to explain the transshipment flows in the data set. It also addressed the endogeneity issue by utilizing the appropriate instrumental variables. The estimation results found the importance to correcting for the endogeneity. They indicated that transshipment volumes are more sensitive to the length of the aircraft turnaround time: The reduction of the aircraft turnaround time by 1 hour would be worth the increase in airport charges by more than $1000 per aircraft. Simulation exercises with respect to the alternative policy scenarios for the Korean airport also confirmed this result. The paper's findings contained important policy implications to airport authorities in the Northeast Asian countries. The paper suggested that investing money for reducing turnaround time at airports be an effective strategy, rather than subsidizing airports to

reduce user charges. When capital is in short supply for investment, it makes sense to raise airport charges, and then to use their profits for capacity expansion and automation including EDI system in order to reduce turnaround time.

One avenue of the future research is to collect disaggregated data by industry product and/or by air cargo type and to check the robustness of our finding. Another avenue of checking the generality of our results is to do a similar work for transshipment hub location competition for North America and Europe.

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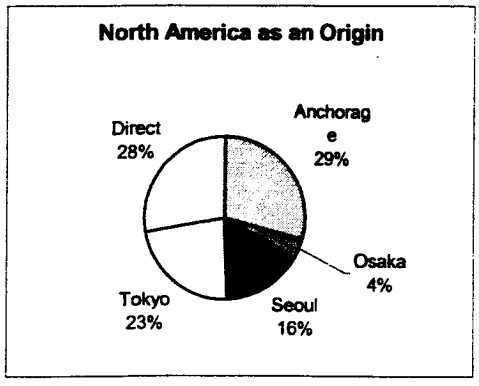
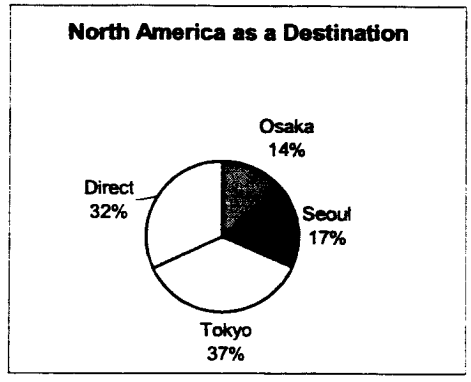
# FIGURE 1

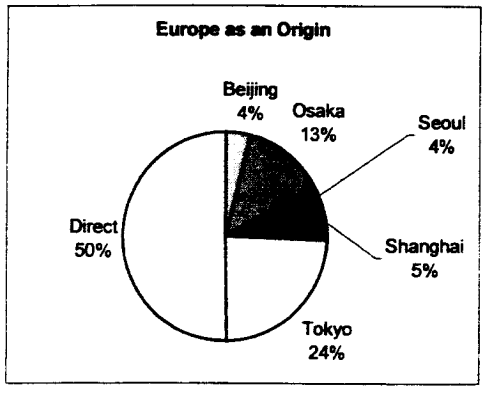
## Direct and Transshipment Shares of Air Cargo: North America - Northeast Asia

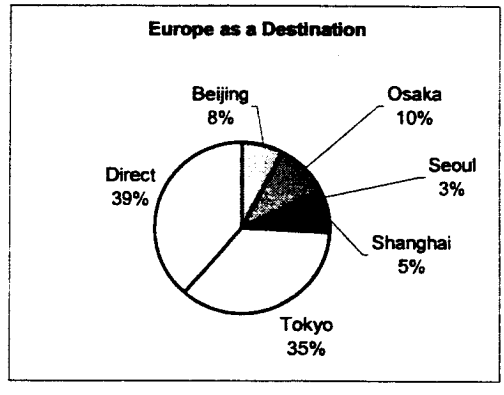


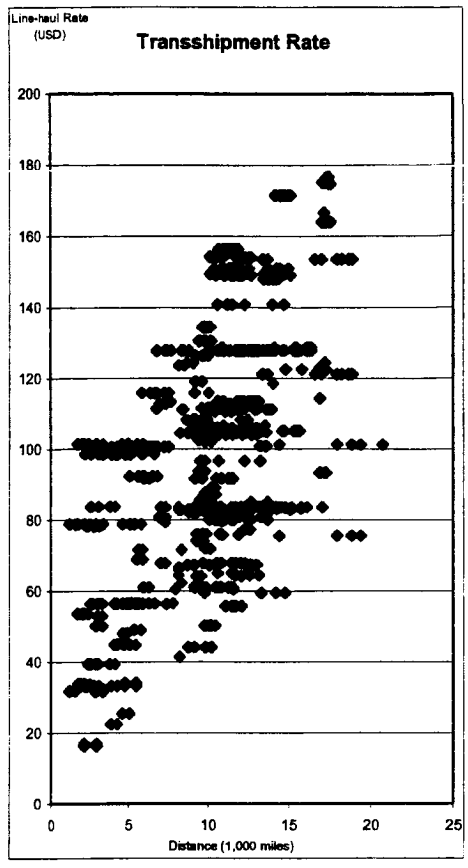

# FIGURE 2

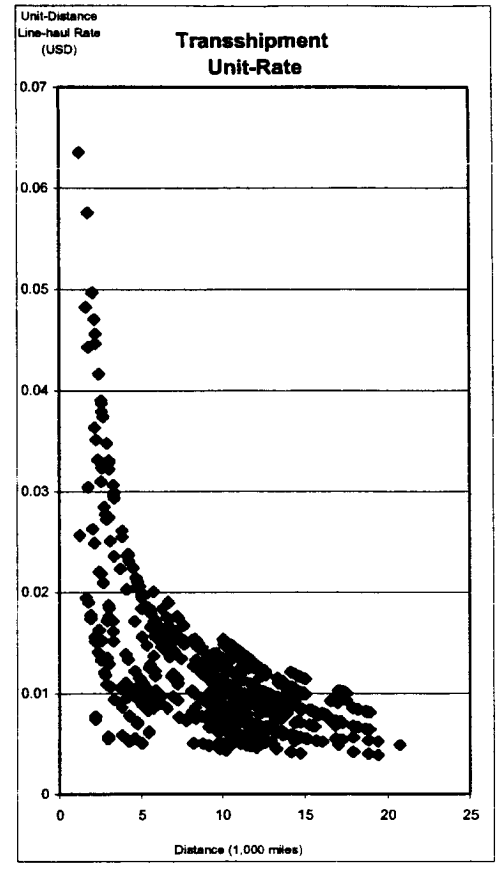
## Direct and Transshipment Shares of Air Cargo: Europe - Northeast Asia

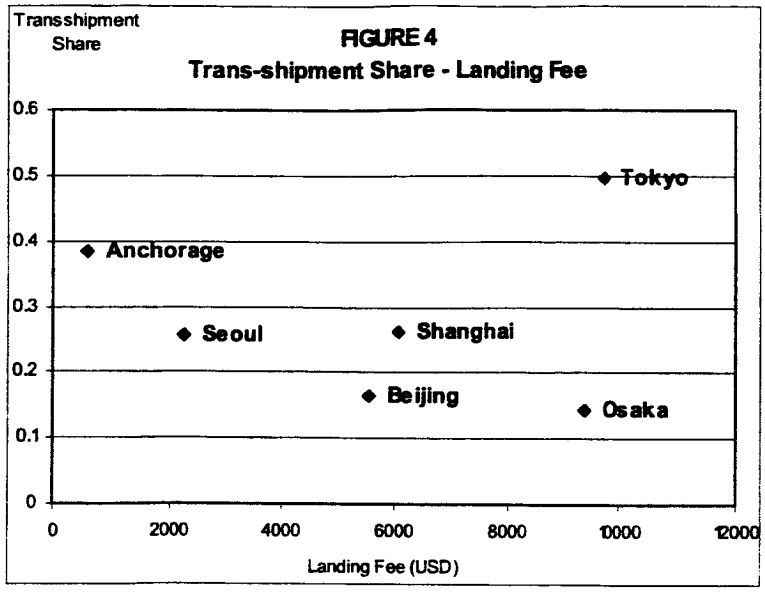


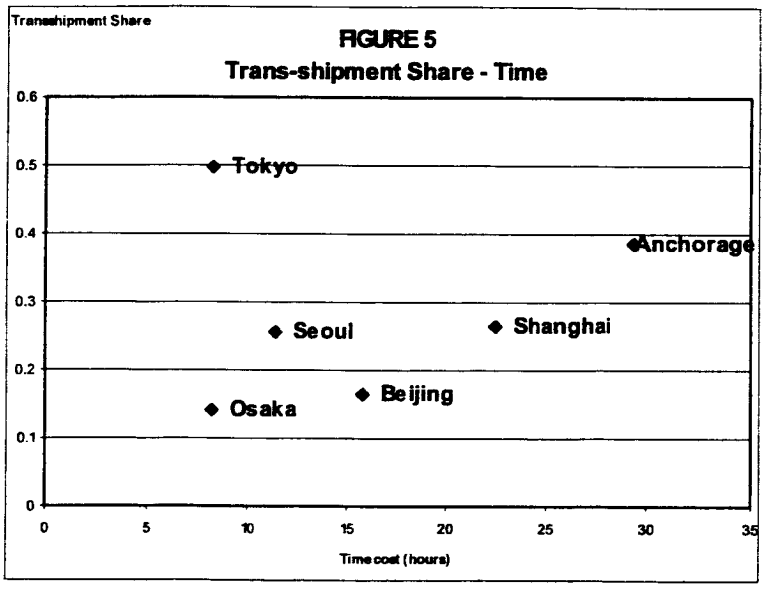



# FIGURE 3
## Line-haul rates and Distance




Transshipment Share
FIGURE 4
Trans-shipment Share - Landing Fee
0.6
0.5
0.4
0.3
0.2
0.1
0
Tokyo
Anchorage
Seoul
Shanghai
Beijing
Osaka
0
2000
4000
6000
8000
10000
12000
Landing Fee (USD)


Transshipment Share
FIGURE 5
Trans-shipment Share - Time
0.6
0.5
0.4
0.3
0.2
0.1
0
Tokyo
Anchorage
Seoul
Shanghai
Beijing
Osaka
0
5
10
15
20
25
30
35
Time cost (hours)

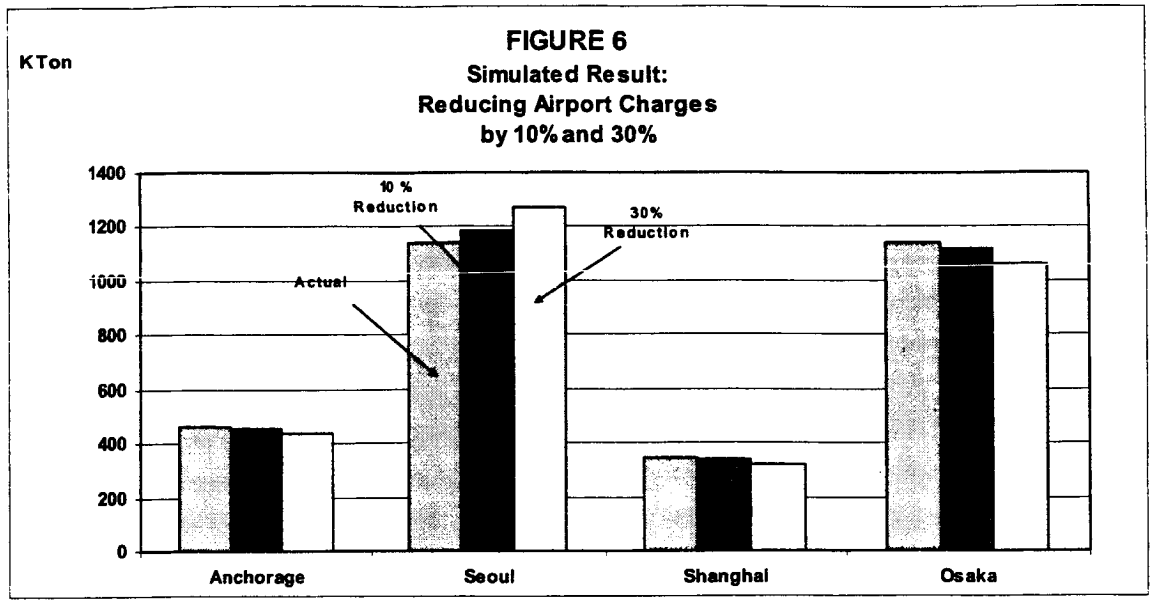



FIGURE 6
Simulated Result:
Reducing Airport Charges
by 10% and 30%

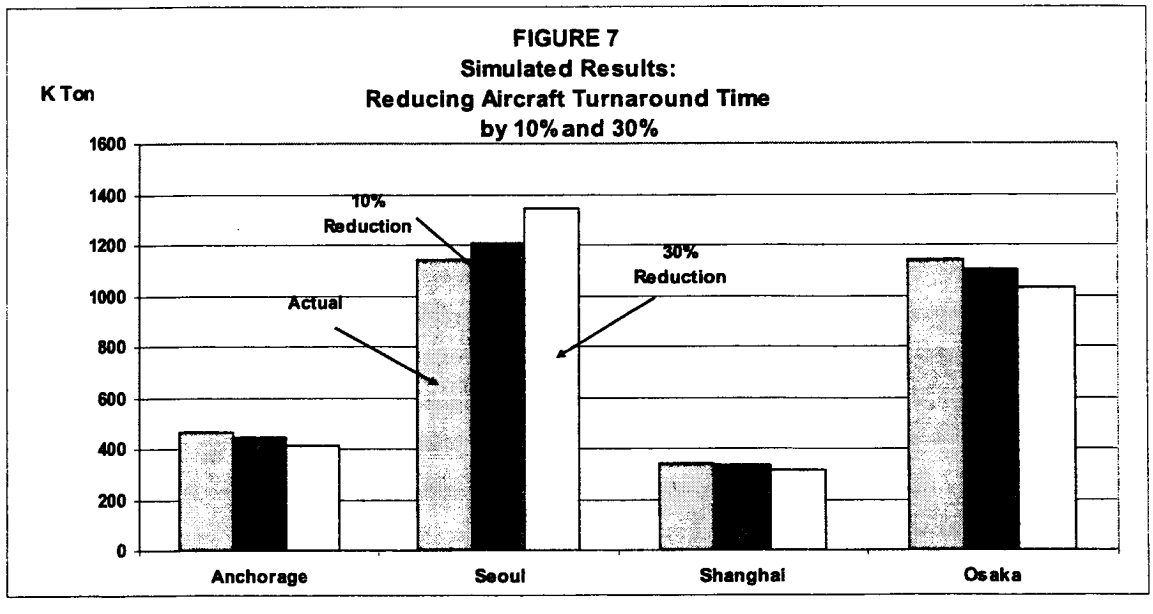



FIGURE 7
Simulated Results:
Reducing Aircraft Turnaround Time
by 10% and 30%

## TABLE 1

### CHARACTERISTICS FOR MAJOR AIRPORTS

### 2000

| Port | Landing fee (USD) | Runways (#) | Capacity (KT per year) | Length of Runway (m) | Cargo Terminal Area (m^2) | Througputs (KT) | Average hours for L/UL & Customs |
|---|---|---|---|---|---|---|---|
| Atlanta | 512 | 4 | 1000 | 3600 | 47740 | 272 | 4.5 |
| Anchorage | 606 | 3 | 4000 | 3800 | 111000 | 1884 | 5 |
| Los Angeles | 1007 | 4 | 3100 | 3650 | 185901 | 1023 | 5 |
| Bangkok | 1114 | 2 | 902 | 3700 | 115969 | 868 | 5 |
| London | 1552 | 3 | 1500 | 4000 | 94000 | 1402 | 4 |
| Chicago | 1576 | 6 | 2000 | 3900 | 190451 | 750 | 4 |
| Seoul | 2249 | 2 | 2700 | 3750 | 183158 | 1891 | 5 |
| Frankfurt | 2672 | 3 | 1600 | 4000 | 22000 | 1710 | 4 |
| Singapore | 2819 | 2 | 2500 | 4000 | 640000 | 1705 | 5 |
| Paris | 4485 | 4 | 2000 | 4215 | 299000 | 1611 | 4 |
| New York | 4646 | 4 | 2000 | 4400 | 106490 | 1339 | 5 |
| Amsterdam | 5144 | 4 | 1500 | 3500 | 270000 | 1267 | 4.5 |
| Beijing | 5547 | 2 | 300 | 3800 | 72800 | 557 | 5 |
| Shanghai | 6084 | 2 | 1750 | 4000 | 146200 | 613 | 5 |
| Sydney | 6292 | 3 | 1500 | 3962 | 140000 | 590 | 5 |
| HongKong | 6905 | 2 | 3000 | 3800 | 28000 | 2001 | 5 |
| Osaka | 9371 | 1 | 1400 | 3500 | 111940 | 864 | 4.5 |
| Tokyo | 9700 | 2 | 1380 | 4000 | 311300 | 1842 | 5 |

## TABLE 2

### DEFINITIONS AND SUMMARY STATISTICS FOR THE VARIABLES

### Airfreight in the Northeast Asian Region, 2000

| Descriptions | Mean | Std. Error | Min | Max |
|---|---|---|---|---|
| **Dependent Variable** | | | | |
| The volume share % on route j in the total transshipment volume in the O-D pair | 22.14 | 25.89 | 0.00001 | 100.00 |
| **Independent Variables** | | | | |
| Shipping Rate (USD) | 92.53 | 32.59 | 16.34 | 176.64 |
| Landing Fee (USD: B747-400 with the weight of 395 tons) | 52.88 | 31.02 | 6.06 | 93.71 |
| Aircraft turnaround Time (hours) | 14.46 | 17.01 | 4.89 | 91.00 |
| Throughput by Airport (K tons) | 1.18 | 0.58 | 0.56 | 1.89 |
| **Instruments** | | | | |
| Length of the Runway (meters) | 3.73 | 0.17 | 3.50 | 4.00 |
| Cargo Terminal Area (squared meters) | 13.32 | 3.95 | 7.28 | 18.32 |
| Distance from the origin port to the destination port via transshipment port (miles) | 0.97 | 0.40 | 0.12 | 2.07 |
| Sum of the competitors' runway length (meters) | 45.04 | 623.49 | 0.00 | 9480 |
| Sum of the competitors' cargo terminal area | 4.55 | 62.75 | 0.00 | 900 |

## TABLE 3
## Route Choice Estimation Results

| | (A) OLS Base | | (B) 2SLS Base | | (C) OLS Gravity | | (D) 2SLS Gravity | |
|---|---|---|---|---|---|---|---|---|
| | Est. | Std. | Est. | Std. | Est. | Std. | Est. | Std. |
| Line haul cost | 0.008 ** | 0.003 | -0.002 | 0.010 | | | | |
| Landing Fee | -0.025 ** | 0.005 | -0.026 | 0.018 | -0.017 ** | 0.005 | -0.039 ** | 0.018 |
| Turnaround Time | -0.109 ** | 0.005 | -0.143 ** | 0.033 | -0.107 ** | 0.005 | -0.179 ** | 0.056 |
| Throughput | -0.658 ** | 0.256 | -0.759 | 0.717 | -0.273 | 0.242 | -1.336 * | 0.790 |
| Distance | | | | | -0.216 | 0.218 | 0.30 | 0.58 |
| Line haul cost for Tokyo | 0.011 * | 0.006 | 0.008 | 0.015 | | | | |
| Landing Fee for Tokyo | -0.019 | 0.089 | -0.059 | 0.153 | -0.020 | 0.072 | -0.079 | 0.222 |
| Turnaround Time for Tokyo | 0.147 ** | 0.055 | 0.259 | 0.285 | 0.184 ** | 0.056 | 0.545 | 0.470 |
| Distance for Tokyo | | | | | 0.637 | 0.430 | -0.474 | 1.223 |
| No. Observations | 760 | | 760 | | 760 | | 760 | |
| R-squared | 0.46 | | 0.41 | | 0.44 | | 0.28 | |
| First stage F statistics | - | | 477.59 ** | | - | | 273.02 ** | |
| J statistics (D.F.) | - | | 16.76 * (7) | | - | | 15.15 (9) | |

Note:
Dependent Variable = $\ln(s_j) - \ln(s_k)$, where j and k are in the same pair of origin and destination.
The landing fee coefficients for Tokyo is multiplied by 1000 for presentation.
First-stage F statistics provide the average explanatory power of the instruments, conditional on the included exogenous variables
J statistics provides an overidentifying restriction test.
* Significance at the 95-percent confidence level.
** Significance at the 99-percent confidence level.

# A Fuzzy approach of the Competition on the air transport market

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**Abstract**

The aim of this communication is to study with a new scope the conditions of the equilibrium in an air transport market where two competitive airlines are operating. Each airline is supposed to adopt a strategy maximizing its profit while its estimation of the demand has a fuzzy nature. This leads each company to optimize a program of its proposed services (frequency of the flights and ticket prices) characterized by some fuzzy parameters. The case of monopoly is being taken as a benchmark. Classical convex optimization can be used to solve this decision problem. This approach provides the airline with a new decision tool where uncertainty can be taken into account explicitly. The confrontation of the strategies of the companies, in the case of duopoly, leads to the definition of a fuzzy equilibrium.

This concept of fuzzy equilibrium is more general and can be applied to several other domains. The formulation of the optimization problem and the methodological consideration adopted for its resolution are presented in their general theoretical aspect.

In the case of air transportation, where the conditions of management of operations are critical, this approach should offer to the manager elements needed to the consolidation of its decisions depending on the circumstances (ordinary, exceptional events,..) and to be prepared to face all possibilities.

**Keywords:** air transportation, competition equilibrium, convex optimization , fuzzy modeling,

## I. INTRODUCTION

The study of the competition between operators in a transportation market has been done in several situations and under multiple hypotheses, the approach here treats this problem in the case where the estimation of demand is fuzzy.

The decision making and the choice of the strategies of an operator either when he is monopolistic or when there is a competition with other operator(s), need an estimation of his share of the market. This estimation of the demand is in general obtained through econometric regressions based on historic data and through statistical methods. In such a case, a crisp function depending on the explicative variables is obtained. Some authors[1] have recently proposed to use fuzzy modeling techniques to represent the uncertainty related with the demand. In this paper, the operators supply decision making process under a fuzzy estimation of demand is investigated and a fuzzy equilibrium situation is considered.

But before the study of the competition, and in the section II, the case of monopoly has been treated in both crisp and fuzzy estimation of demand function.

## II. MONOPOLY: CHOICE OF PRICE AND SUPPLY

Let consider first a transport market where only one operator is acting. This operator has to choose the level of its supply Q and its price p, in order to maximize its profit $\pi$. The market is characterized by a demand function D(p) and the operations cost which is supposed to be a function of the level of operator's supply Q and is denoted C(Q). The satisfied demand is given by: $\min\{D(p), Q\}$ and the profit is equal to: $\pi = p.\min\ D(p) - C(Q)$. Here the demand is supposed independent of the supply level and is assumed to depend only on the price.

When an estimation $\hat{D}(p)$ of the demand function is available, the program of the operator is:

$$\underset{p,Q}{Maximize} \quad p.\min\ \hat{D}(p) - C(Q)$$

In this part, two cases are treated: first, the classical case, in which demand is considered as a crisp perfectly known function, is recalled. Then the analysis of the case of a fuzzy estimation of the demand function is developed

### *A. Demand as a crisp function*

It is assumed, in this first part, that $\hat{D}(p)$ is a crisp function and that the cost function is also exactly known by the operator.

The illustration of the displayed concepts will be achieved in the linear case (linear demand and cost functions).

***Illustration:***

For simplicity, these demand and cost functions are assumed to be linear:

$D(p) = D_0 - \lambda . p$ , for $0 < p_{min} \le p \le p_{max} \le D_0 / \lambda$,

where $D_0$, $\lambda$, $p_{min}$ and $p_{max}$ are strictly positive parameters.

And $C(Q) = c_0 + c.Q$ for $0 < Q \le Q_{max}$ ,

where c, $c_0$ and $Q_{max}$ are strictly positive parameters, $c_0$ is the fixed cost, c is a constant marginal cost and $Q_{max}$ is the supply capacity of the operator. It is supposed in this study that the lower and upper bounds of p and Q are never reached. The program of the company is:

$\underset{p,Q}{Maximize}\ p.\min\ D_0 - \lambda Q - c_0$ [illegible]

Two cases are considered, depending on the nature of the satisfied demand:

### 1) 1st case: D(p)≤Q

In this case, the demand is considered to be not limited by the level of supply but by the price level and the profit of the operator is given by: $\pi(p,Q) = p.D(p) - C(Q)$, for a given price p.

$\pi$ decreases when Q increases (for a given p) so the couple (p,Q) achieving the maximum profit for this case takes place when Q is exactly equal to D(p). The problem reduces here to:

$$\begin{cases} \underset{p}{Max} & p.D(p) - C(D(p)) \\ \text{such that} & D(p) \le Q \end{cases}$$

The resolution of such a program is more or less hard de pending on the respective expressions of the demand and cost functions.

*Application to the linear case:*
*In this case, optimality is obtained from the first and second order Lagrange conditions.*
*The first order Lagrange's condition :* $\partial\pi / \partial p = 0$
*Leads to a unique solution:* $p^* = c/2 + D_0 / 2\lambda$
*and since the second order condition*

$$\partial^2\pi / \partial p^2 = -2\lambda < 0$$

*is always satisfied, this value of price* $p^*$ *is optimal for this program.*
*The corresponding level of supply is equal to:*

$$Q^* = (D_0 - \lambda c)/2$$

*Observe that this equality supposes that* $D_0 > \lambda c$. *The optimal profit can then be written as:*

$$\pi^* = ((D_0 - \lambda c)/2)^2 / \lambda - c_0 \qquad (1)$$

### 2) 2nd case: D(p) ≥Q

In this case, the satisfied demand is limited by the level of supply and the program of the company becomes:

$$\begin{cases} \underset{p,Q}{Max} & p.Q - C(Q) \\ & D(p) \ge Q \end{cases}$$

*Application to the linear case: here the assumption* $D(p) \ge Q$, *implies an upper limit for p:* $p \le (D_0 - Q)/\lambda$. *When p increases and Q stays unchanged, the profit increases so the optimal value for p is equal to its maximum allowed value that is to say:* $p^* = (D_0 - Q)/\lambda$.
*Then the profit can be expressed as a function of Q, only; and it can be maximized with respect to the level of supply. The optimality conditions lead to the same expression for the expected profit as in the first case as expressed in (1).*

*B. Fuzzy estimation of demand:*

In this subsection, the estimation of the demand adopted by the company is considered as fuzzy. For a given price, $\tilde{D}(p)$ is for simplicity assumed to be represented by a trapezoidal

fuzzy number. Figure: fig.1 sketches such a function by showing for the interval $p_{min}$ $p_{max}$ "level curves" of $\tilde{D}(p)$: $D_2$ and $D_3$ are the curves for which the degree of membership becomes equal to 1, $D_1$ and $D_4$ are the curves for which the grade of membership starts from zero (see fig1'). For consistency reasons, these four functions are supposed not to intersect on the domain $p_{min}$ $p_{max}$ .

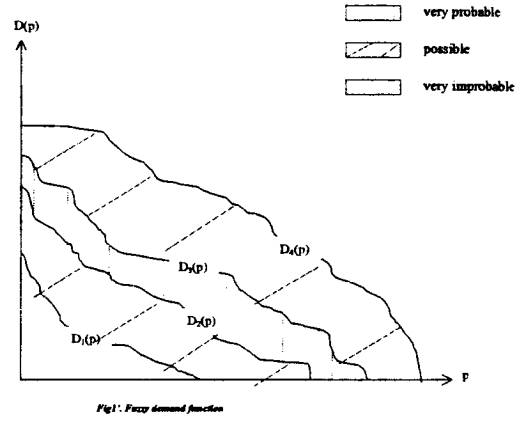



Fig1': Fuzzy demand function

For every price p in the allowed domain, the membership function $\mu_D^p$ of the demand d, represented by fig. 2. is defined as follows:

$$\begin{cases} \dfrac{d - D_1(p)}{D_2(p) - D_1(p)} & \text{if } D_1(p) \le d \le D_2(p) \\ 1 & \text{if } D_2(p) \le d \le D_3(p) \\ \dfrac{d - D_4(p)}{D_3(p) - D_4(p)} & \text{if } D_3(p) \le d \le D_4(p) \\ 0 & \text{if } d \le D_1(p) \text{ or } d \ge D_4(p) \end{cases}$$

The fuzziness of demand propagates to the profit of the operator and when this latter chooses the couple (p,Q), he should get a fuzzy estimation of his profit $\tilde{\pi}$ .

Let $\tilde{s}^{p,Q}$ be the fuzzy estimation of the satisfied demand corresponding to (p,Q): $\tilde{s}^{p,Q} = \min(\tilde{D}(p), Q)$; the membership function of $\tilde{s}^{p,Q}$ is denoted $\mu_s^{p,Q}$, this membership function is deduced from the one of $\tilde{D}(p)$ :

$\mu_s^{p,Q}(s) = \mu_D^p(s)$ if $s < Q$,

$$\mu_s^{p,Q}(Q) = \left[ \min_{d \ge Q} \mu_D^p(d), \max_{d \ge Q} \mu_D^p(d) \right]$$

and $\mu_s^{p,Q}(s) = 0$ if $s > Q$

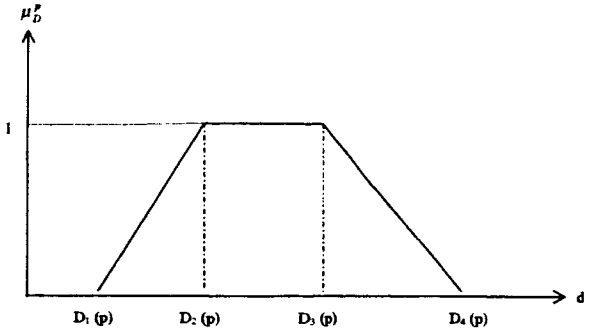



Fig.2: Trapezoidal Membership function of the demand

Then the fuzzy estimation of the profit of the company corresponding to the couple (p,Q) is given by:

$$\tilde{\pi}(p,Q) = p\tilde{s}^{p,Q} - C(Q)$$

And the membership function $\mu_\pi^{p,Q}(\pi)$ of $\tilde{\pi}(p,Q)$ is obtained from the one of s as follows:

$$\mu_\pi^{p,Q}(\pi) = \mu_s^{p,Q}[(\pi + C(Q))/p]$$

To every feasible couple (p,Q), corresponds a fuzzy set representative of the distribution of the estimate of the corresponding profit. To solve its decision problem, the company has to choose a couple (p, Q). It is not possible to compare directly fuzzy numbers, however, since demand is expected to be represented by a convex fuzzy set, it will be the case also for the profit and different possibilities appear to rank convex fuzzy sets: ranking according to the barycenter of the fuzzy set, or by more sophisticated methods as in [3] . In a simpler consideration, and when the fuzzy numbers are normalized, which is the case here (in fact, here for every (p,Q), there exists at least a $\pi$ such as $\mu_\pi^{p,Q}(\pi) = 1$ ( $\pi / \mu_\pi^{p,Q}(\pi) = 1 \neq \phi$) (as shown by figures 3.), fuzzy numbers can be ranked according to the barycenter of the values whose membership is equal to1.

In this case, the calculation of the expected profit imposes the consideration of five different profit subsets configurations: depending on the shape of the membership function of $\tilde{s}$ as it is sketched by the five figures 3.

- 1st case: $Q \geq D_4(p)$ ; ( a trapeze, fig.3a)
- 2nd case: $D_3(p) \leq Q \leq D_4(p)$ ; (a pentagon, fig.3b)
- 3rd case: $D_2(p) \leq Q \leq D_3(p)$ , ( rectangular trapeze, fig.3c)
- 4th case: $D_1(p) \leq Q \leq D_2(p)$ ; (a union of a triangle with a vertical segment, fig.3d)
- 5th case: $Q \leq D_1(p)$ , (a vertical segment, fig.3e).

The expected profit is here taken as the barycenter of the fuzzy base of $\pi$.

Let $\pi_e$(p,Q) be the surrogate value adopted to rank the expected profits. Once a couple (p*,Q*) such as:

$$\pi_e(p^*, Q^*) = \underset{p,Q}{Max}\ \pi_e(p,Q)$$

has been found, a fuzzy estimation of the best expected profit is given by the membership function $\mu_\pi^{p^*,Q^*}(\pi)$.

An alternate approach, a conservative one, could be, instead of trying to maximize the profit, to minimize the possible loss, according to fig.4. It is possible to assign too, to each couple (p, Q), a measure of this risk.

*Application to the linear case: for simplicity, these four functions are assumed to be linear:*

$D(p) = D_{i0} - \lambda_i p$ , $i \in 1,2,3,4$ $p_{min} \le p \le p_{max}$ *(see fig. 5)*

*here* $D_{i0}$ *and* $\lambda_i$ *are positive parameters.* $(D_{i0})_{1\le i\le 4}$ *and* $(D_{i0}/\lambda_i)_{1\le i\le 4}$ *are taken as increasing sequences (these functions do not intersect on* $p_{min}$ $p_{max}$ *).*

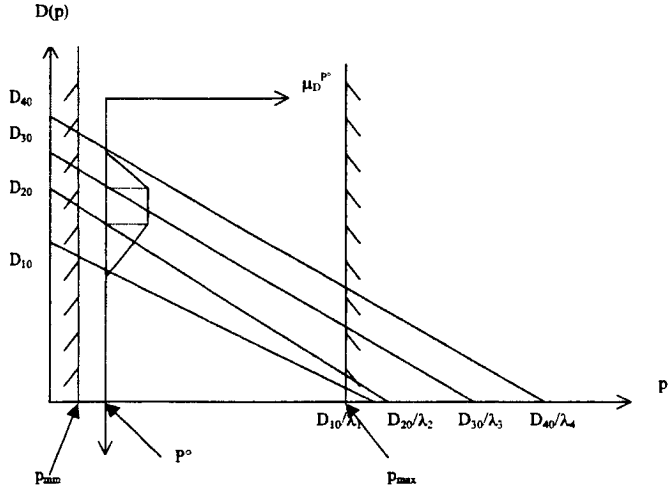



**Fig5 : fuzzy demand function . linear case**

## III. COMPETITION UNDER DUOPOLY

Here, it is supposed that two companies are operating on the same market. Each company i ($i\in\{1,2\}$), attracts a demand $D_i$ depending on the prices $p_1$ and $p_2$ of both companies and produces a supply level denoted $Q_i$ which costs to it $C_i(Q_i)$. These operators are supposed not to co-operate but to compete playing a Cournot game. The 'Cournot' equilibrium of a such game is studied in this section. The case of crisp demand functions of the two operators is revisited in a first part and then the case of fuzzy estimation of the demands is treated in the second part

Every firm i ($i \in \{1,2\}$)will suppose that the parameters $p_{j\neq i}$ and $Q_{j\neq i}$ are known, and will choose its price $p_i$ and supply level $Q_i$ that maximize its profit $\pi_i$ depending on these values.

When an estimation of the demand function $\tilde{D}_i(p_1,p_2)$ is given, the program of the company i is then

$$\begin{cases} \max\limits_{p_i,Q_i} \quad p_i \cdot \min\ \tilde{D}_i(p_1,p_2),Q_i - C_i(Q_i) \\ p_{j\neq i} \text{ and } Q_{j\neq i} \text{ are taken as known.} \end{cases}$$

the case of crisp demand functions of the two operators is revisited in a first part and then the case of fuzzy estimation of the demands is treated in the second part.

### *A. Demand as a crisp function:*

It is assumed in this first part that $\tilde{D}_1(p_1,p_2)$ and $\tilde{D}_2(p_1,p_2)$ are crisp functions and the cost functions $C_1(Q_1)$ and $C_2(Q_2)$ are exactly known by the operators

*Application: demand and cost as linear functions:*
*Here again, the demand and cost functions of both companies are assumed to be linear:*

$D_i(p_i, p_j) = D^i{}_0 - \lambda_i . p_i + \mu_i p_j$, *for* $0 < p^i_{min}(p_j) \le p_i \le p^i_{max}(p_j) \le D_{i0}/\lambda_i + (\mu_i/\lambda_i)p_j$, $i \in 1,2$ -

*where* $D_{i0}, \lambda_i, \mu_i (<\lambda_i)$, $p^i_{min}$ *and* $p^i_{max}$ *are strictly positive parameters for* $i \in 1,2$ -.

$C_i(Q_i) = c_{i0} + c_i . Q_i$ *for* $0 < Q_i \le Q^i_{max}$ , $i \in 1,2$ -.

*where* $c_i$, $c_{i0}$ *and* $Q^i_{max}$ *are strictly positive parameters,* $c_{i0}$ *is the fixed cost,* $c_i$ *is a constant marginal cost for the firm i and* $Q^i_{max}$ *is its supply capacity. It is supposed here that the lower and upper bounds of* $p_i$ *and* $Q_i$ *are never reached. The program of the ith company (*$i \in 1,2$ -*) becomes:*

$$\begin{cases} \underset{p_i, Q_i}{Max\ imize} \quad p_i . \min D_{i0} + \sum_{j \neq i} p_{j \neq i} - \lambda_i . p_i, Q_i - c_{i0} \sum Q_i \\ \text{where } (p_j . , Q_j) \text{ is the solution of the program of the other company } (j \neq i). \end{cases}$$

Two cases are considered, depending on the nature of the satisfied demand by firm i:

*1st case:* $D_i(p_i, p_j) \le Q_i$
In this case, the demand is considered to be not limited by the level of supply but by the price level. The profit of the company i is given by:

$$\pi_i((p_i, Qi)/p_j) = p_i . D_i(p_i, p_{j \neq i}) - C_i(Q_i).$$

$\pi_i$ decreases when $Q_i$ increases (for a given $p_i$) so the couple ($p_i$, $Q_i$) achieving the maximum profit for this case takes place when $Q_i$ is exactly equal to $D_i(p_i, p_j)$.
The problem reduces here to:

$$\begin{cases} \max\limits_{P_i} \quad p_i . D_i(p_i, p_{j \neq i}) - C_i(D_i(p_i, p_{j \neq i})) \\ p_j \quad \text{is as given} \end{cases}$$

*2nd case:* $D_i(p_i, p_{j \neq i}) \ge Q_i$
In this case, the satisfied demand is limited by the level of supply and the program of the company becomes:

$$\begin{cases} \underset{p_i, Q_i}{Max} \; p_i . Q_i - C_i(Qi) \\ D_i(p_i, p_j) \ge Q_i \\ p_j \text{ is as given} \end{cases}$$

In both cases, the resolution of the associated program and the study of the existence of an equilibrium are more or less difficult, depending on the respective expressions of the demand and cost functions. The relationship between $p_i$ and $p_j$ could be studied for different levels of market share ($MS_i = D_i/(D_i + D_j)$)(respectively for different levels of profit $\pi_i$). Isomarketshare(resp. isoprofit) curves could be dressed.

*Application to the linear case:*

*As it has been shown in the first section, when the functions are linear, both cases lead to the same solution:*

$$p_i^* = c_i / 2 + (Di_0 + \mu_i p_j) / 2\lambda_i$$

$$Q_i^* = (D_{i0} + \mu_i p_j - \lambda_i c_i) / 2$$

*for* $i, j \in 1,2$ ,*i* ≠ *j*

*The ith optimal profit can then be written as:*

$$\pi_i^* = ((D_{i0} + \mu_i p_j - \lambda_i c_i) / 2)^2 / \lambda_i - c_{i0} \qquad (1')$$

*In conclusion, the ith optimal program is such as:*

$$p_i^* = (c_i + D_{i0} / \lambda_i + (\mu_i / \lambda_i) p_j) / 2 \quad , \quad Q_i^* = (D_{i0} + \mu_i p_j - \lambda_i c_i) / 2$$

*where* $j \in 1,2$ ,*j* ≠ *i*

*It* corresponds to a Cournot equilibrium which is also here a Nash equilibrium.

$p_1^* = (c_1 + D_{10} / \lambda_1 + (\mu_1 / \lambda_1) p_2) / 2$ *and* $p_2^* = (c_2 + D_{20} / \lambda_2 + (\mu_2 / \lambda_2) p_1) / 2$

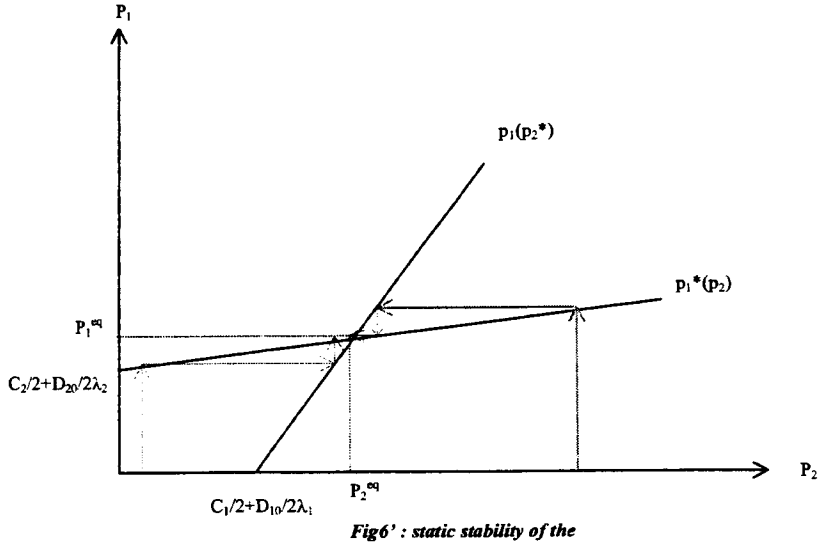



***Fig6' : static stability of the equilibrium***

$$MS_i = D_i(p_i, p_j) / (D_i(p_i, p_j) + D_j(p_i, p_j))$$

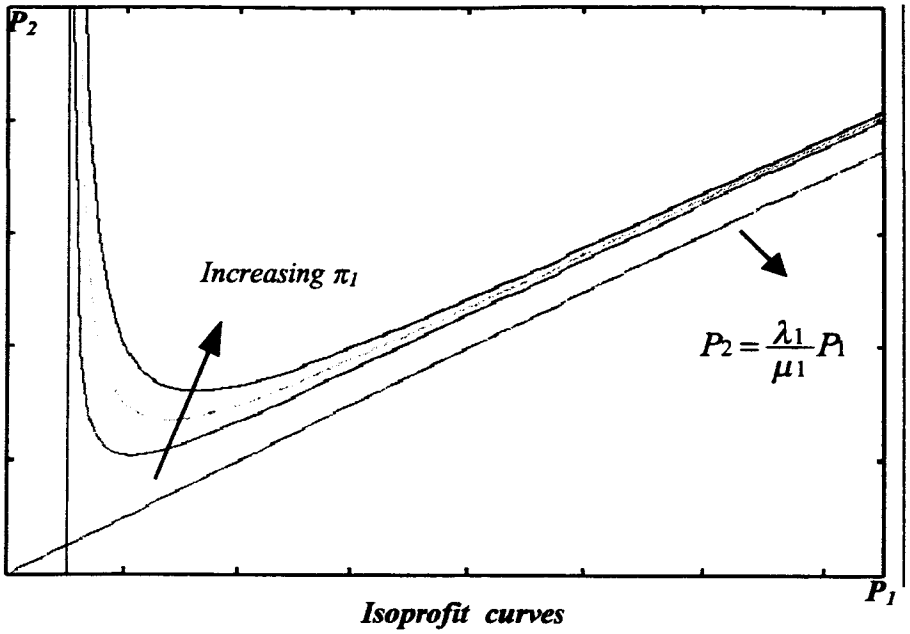
$$= (D_{i0} - \lambda_i . p_i + \mu_i p_j) / (D_{i0} + D_{j0} - \lambda_i . p_i + \mu_j p_i - \lambda_j . p_j + \mu_i p_j)$$

$$\Rightarrow (MS_i(\mu_i - \lambda_j) - \mu_i) p_j = (MS_i(\mu_j - \lambda_i) - \lambda_j) p_i + D_{i0} - MS_i(D_{i0} + D_{j0})$$

$$\pi i = p_i D_i(p_i, p_j) - C(Q_i)$$

$$\Rightarrow \pi_i = (p_i - c_i)(D_{10} - \lambda_i p_i + \mu_i p_j) - c_{i0}$$

$\Rightarrow$ *for* $p_i \neq c_i$, $p_j = (\lambda_i p_i^2 + (D_{i0} - \lambda_i c_i) p_i + \pi_i + c_{i0} + c_i D_{i0}) / \mu_i (p_i - c_i)$, *for a given level of profit* $\pi_i$. *The figure below sketches the isoprofit cruves giving relationship between p2 and p1.*




***Isoprofit curves***

***B. fuzzy Demand functions***

In this subsection, the estimation of the demand adopted by each company is considered as fuzzy. For a given couple of prices $(p_1, p_2)$, $\tilde{D}_i(p_1, p_2)$ is assumed to be represented by a trapezoidal fuzzy number. On the domain $p_1^i \; p_{\max}^i \; X \; p_2^j \; p_{\max}^j$, some "level mappings" of $\tilde{D}_i(p_1, p_2)$ can be pointed out:

- $D_i^b$ and $D_i^c$ are the surfaces where the degree of membership of $d_i$ becomes equal to 1.
- $D_i^a$ and $D_i^d$ are the surfaces where the grade of membership of $d_i$ starts from zero.
- For coherency, these sets cannot intersect.

*Application: to the linear case:*
*Here the level mappings are such as:*

$$D_i^k(p_i, p_j) = D_i^k - \lambda_i^k p_i + \mu_i p_j, \qquad (i, j \neq i) \in 1,2^{\frac{2}{}}, \qquad k \in a, b, c$$

$(p_i, p_j) \in p_1^i \; p_{\max}^i \; x \; p_2^j \; p_{\max}^j$

*here $D_i^k$, $\lambda_i^k$ and $\mu_i^k$ ($<\lambda_i^k$) are positive parameters. $(D_i^k)_{k \in a,b,c}$ and $(D_i^k / \lambda_i^k)_{k \in a,b,c}$ are taken as increasing sequences so that these functions do not intersect, it is also assumed that for every $k \in a, b, c$, the rate $\lambda_i^k / \mu_i^k$ is a constant equal to a real $\alpha_i$ (>1). The firm i will take the price and the supply level of the firm j as known and it will face a program analogous to the one treated in the example given in the case of monopoly. And it is the same for the firm j. Does this situation have an equilibrium?*
*A first approach of this problem consists to fuzzify solutions found in the crisp case(see fig.7):*

$p_1^* = (c_1 + \tilde{D}_{10} / \tilde{\lambda}_1 + (\tilde{\mu}_1 / \tilde{\lambda}_1) p_2) / 2 \quad , \quad p_2^* = (c_2 + \tilde{D}_{20} / \tilde{\lambda}_2 + (\tilde{\mu}_2 / \tilde{\lambda}_2) p_1) / 2$

$Q_1^* = (\tilde{D}_{10} + \tilde{\mu}_1 p_2 - \tilde{\lambda}_1 c_1) / 2 \; , \; Q_2^* = (\tilde{D}_{20} + \tilde{\mu}_2 p_1 - \tilde{\lambda}_2 c_2) / 2$

*with $\tilde{D}_{i0}, \tilde{\lambda}_i$ and $\tilde{\mu}_i$ are fuzzy parameters (as described here $D_i^k$ and $\lambda_i^k$ are positive parameters. $(D_i^k)_{k\in a,b,c}$ and $(D_i^k / \lambda_i^k)_{k\in a,b,c}$ are taken as increasing sequences)*

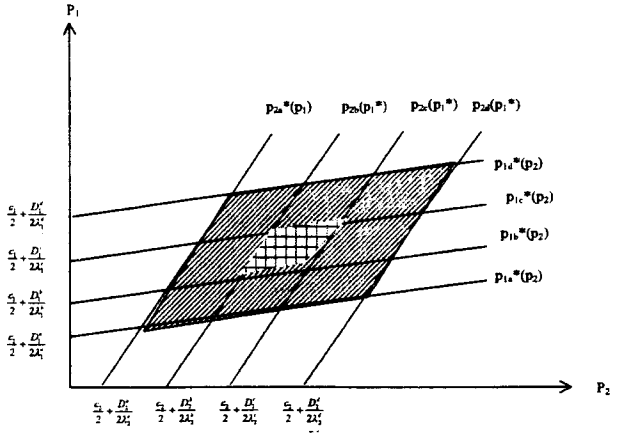



*Fig7*

Another approach is to consider the problem as in the first part of the paper (case of monopoly) where a fuzzy profit is considered. Through defuzzyfication (for example as a barycenter depending on the shape of the membership function of the satisfied demand,..) one expected profit can be obtained for each firm i associated with the pairs $(p_i, Q_i)$ and $(p_j, Q_j)$, i≠j : $\pi_i^e(p_i, Q_i, p_{j\neq i}, Q_{j\neq i})$ . It can be then maximized with respect to $p_i, Q_i$, an optimized profit will be obtained : $\pi_i^{e*}(p_{j\neq i}, Q_{j\neq i})$ and the couple $(p_i^*(p_{j\neq i}, Q_{j\neq i}), Q_i^*(p_{j\neq i}, Q_{j\neq i}))$ realizes this maximum and then the firm will expect a fuzzy profit $\tilde{\pi}_i(p_i^*(p_{j\neq i}, Q_{j\neq i}), Q_i^*(p_{j\neq i}, Q_{j\neq i}))$ .

An eventual equilibrium could be defined by the confrontation of these expressions of solutions:

$$\begin{cases} (p_1^*(p_2, Q_2), Q_1^*(p_2, Q_2)) \\ (p_2^*(p_1, Q_1), Q_2^*(p_1, Q_1)) \end{cases}$$

In this approach the values of the prices and the levels of supplies are defined in a crisp way and to them are associated fuzzy profits as in the case of monopoly. But in the first approach, for every couple of prices correspond two degrees of membership and then for each company a fuzzy profit is associated .

## IV. CONCLUSION

A new approach of the resolution of the decision problem of firms has been introduced. Several domains can use it especially airlines to choose their frequency and ticket prices. The main advantage of this 'fuzzy' approach is to let the firm be prepared to all possible events and to take into account the optimistic as the pessimistic attitudes when estimating the expected demand addressed to the firm.

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*Figures:*

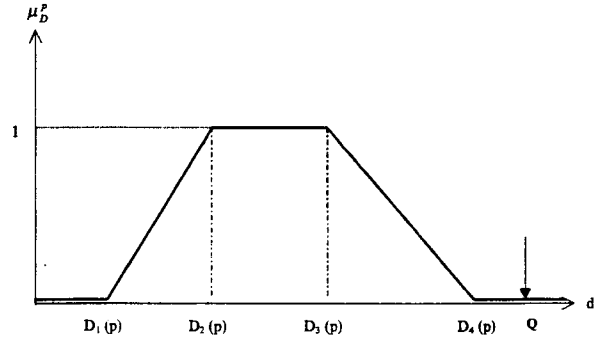


**Fig.3a:** Membership function of the satisfied demand ($Q>=D_4(p)$)

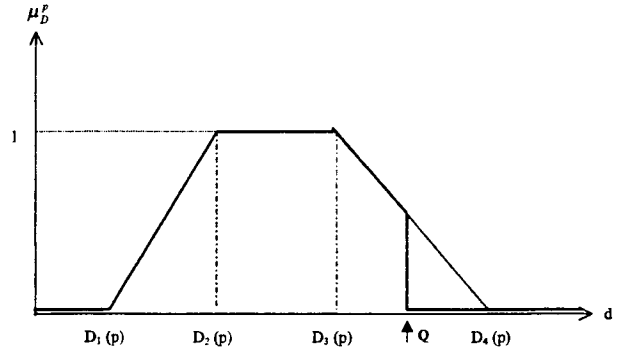


**Fig.3b:** Membership function of the satisfied demand ($D_3(p)<=Q<D_4(p)$)

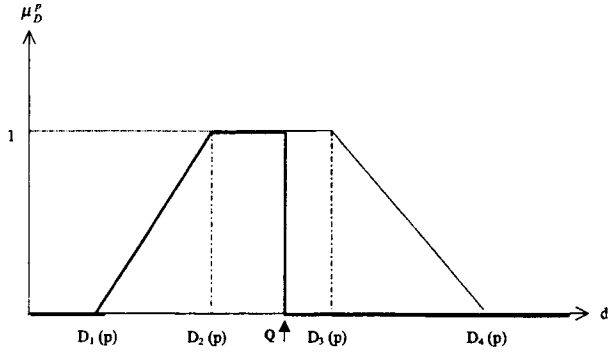


**Fig.3c:** Membership function of the satisfied demand ($D_2(p)<=Q<D_3(p)$)

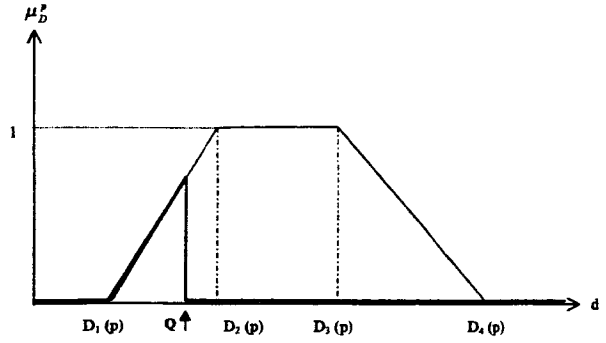


**Fig.3d:** Membership function of the satisfied demand ($D_1$ (p)<=Q<$D_2$ (p))

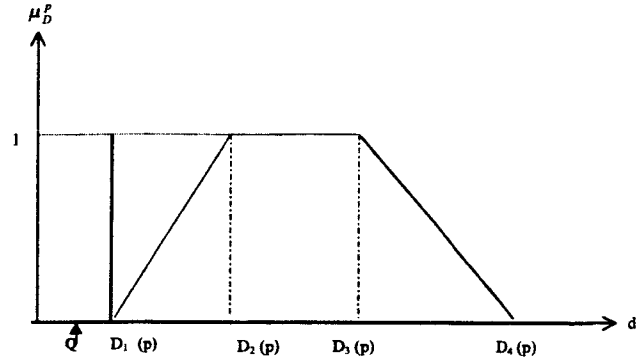


**Fig.3e:** Membership function of the satisfied demand (Q<$D_1$ (p))

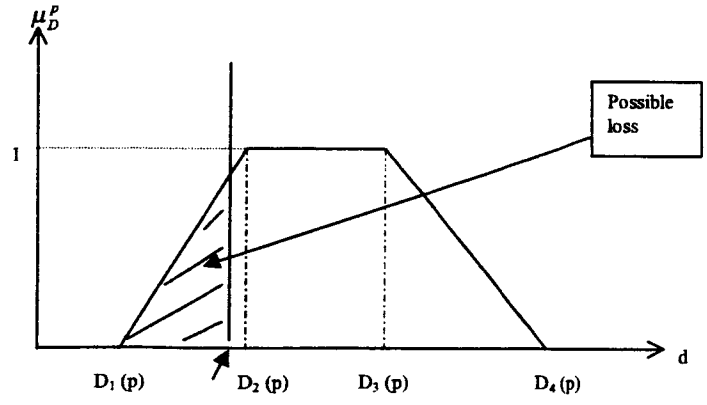


Fig.4

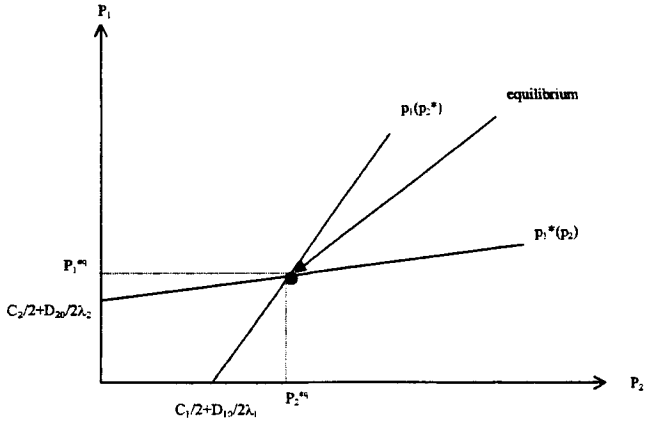


*Fig6*

# DEVELOPING PASSENGER DEMAND MODELS FOR INTERNATIONAL AVIATION FROM/TO EGYPT: A CASE STUDY OF CAIRO AIRPORT AND EGYPTAIR

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## ABSTRACT

This research is concerned with developing passenger demand models for international aviation from/to Egypt. In this context, aviation sector in Egypt is represented by the biggest and main airport namely Cairo airport as well as by the main Egyptian international air carrier namely Egyptair. The developed models utilise two variables to represent aviation demand, namely total number of international flights originating from and attracted to Cairo airport as well as total number of passengers using Egyptair international flights originating from and attracted to Cairo airport. Such demand variables were related, using different functional forms, to several explanatory variables including population, GDP and number of foreign tourists. Finally, two models were selected based on their logical acceptability, best fit and statistical significance. To demonstrate usefulness of developed models, these were used to forecast future demand patterns.

**Key Words:** Passenger, International Flights, Demand Models, Cairo Airport, Egyptair

## 1. INTRODUCTION

The main aim of this research is to develop demand models for passenger aviation from/to Cairo airport. In pursuing this objective, the research starts by drawing a conceptualisation of the main factors affecting passenger demand for international air transport from/to Egypt. In addition, another conceptualisation is drawn portraying the factors influencing the selection of Egyptair, as a potential international carrier, by passengers. Following this a data collection exercise is conducted, whereby historical data, spanning over the 11 years 1990 to 2000, concerning aviation demand variables as well as other explanatory variables thought to affect this demand is collected and compiled from several sources.

Demand variables include number of international flights (scheduled or unscheduled) as well as number of passengers using international Egyptair flights (scheduled or unscheduled) originating from or attracted to Cairo airport. Demand variables are historically plotted in an effort to determine the most proper and representative ones. On the other hand, a number of explanatory variables affecting demand are also selected, namely population, Gross Domestic Product (GDP), number of foreign tourists, GDP/Capita, number of Egyptian pilgrims, number of Egyptian immigrants, as well as number of Egyptians working abroad. A correlation matrix is then computed to obtain values of Pearson correlation coefficient showing the extent of relation between demand variables and the selected explanatory variables. The matrix demonstrates the collinearity between population and pilgrims as well as between GDP and GDP/capita. In addition the matrix shows the illogical negative sign of correlation coefficients relating demand to other explanatory variables such as number of Egyptian immigrants or Egyptians working abroad. Based on these analyses, it is decided to develop demand models relating air passenger demand to population, GDP and number of foreign tourists.

These dependent and independent variables are utilized to calibrate single as well as multiple variable models, using different functional forms, in an effort to represent changes in air passenger demand. All of the calibrated models are subjected to a number of logical and statistical tests. To establish goodness of fit and statistical significance of the calibrated models two statistical indicators are computed namely the $R^2$ and the F-statistic. Finally, models including population and number of foreign tourists as independent variables are selected as being the most logical and statistically significant models. The research concludes with a demonstration of the usefulness of the selected models in terms of ability to predict future passenger demand levels.

## 2. FACTORS AFFECTING PASSENGER DEMAND FOR TRAVELLING BY AIR FROM/TO EGYPT

A conceptualisation of the main factors affecting the demand for travelling by air from/to Egypt is depicted in figure 1. Aviation demand to/from Egypt is composed of Egyptian passengers as well as of foreign passengers. It can be represented by the number of international flights to/from Egypt or by the number of passengers using international flights to/from Egypt. Ten factors were identified as affecting the demand generated by

Egyptian nationals and attracted to other countries. Three can be grouped under socio-economic factors. These include population size, GDP, and GDP/Capita in Egypt. The increase in any of these factors is expected to generate more demand for travelling by air. One factor is related to a pillar of the Islamic religion, namely performance of Haij (pilgrimage). Each year, and according to quota, Saudi Arabia grants a number of Haij visas equivalent to 0.001 of the Egyptian population. Egyptian pilgrims travel to the holy cities of Makkah and Madina in Saudi Arabia in order to perform Haij. Haij takes place once a year during the Arab month of Zou Al-Haija. In addition, Omra another Islamic ritual and a smaller version of Haij, can be performed at any time of the year but its peak season is during the Arabic month of Ramadan. Egyptians are known to be very frequent in travelling to Saudi Arabia to perform Omra. The other sixth factors are all related to attractions abroad, including:

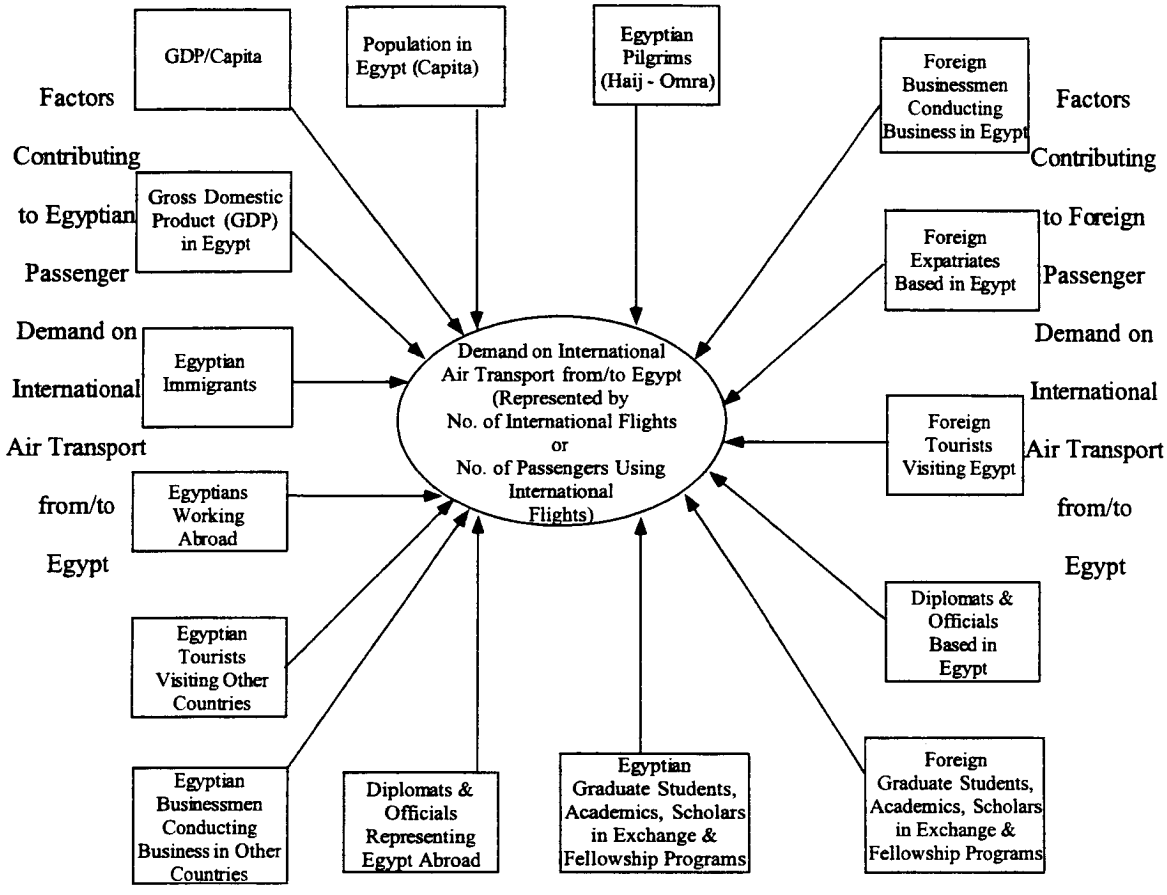
- Egyptians immigrants travelling to/from countries of immigration such as USA, Australia.
- Egyptians working abroad and travelling to/from working destinations, such as Saudi Arabia and other gulf countries.
- Egyptian tourists visiting other countries, especially in summer when lots of Egyptians travel to countries such as Turkey, UK and Greece.
- Egyptian businessmen travelling to countries to conduct business meetings and arrangements
- Diplomats and officials representing Egypt abroad.
- Egyptian graduate students, academics, and scholars travelling to other countries for higher education, research and exchange programs.

On the other hand, five factors were identified as affecting the demand generated by foreign nationals and attracted to Egypt including:

- Foreign tourists attracted to Egypt to visit historical and archaeological Egyptian heritage.
- Foreign nationals, probably expatriate, working in Egypt.
- Foreign businessmen travelling to Egypt to conduct business meetings and arrangements.
- Foreign diplomats and officials representing foreign countries and international bodies within foreign diplomatic missions based in Egypt.
- Foreign graduate students, academics, and scholars travelling to Egypt for higher education, research and exchange programs.

The most important of these five factors is the number of foreign tourists expected to visit Egypt. It is well known that the majority of foreign tourists arrive to and leave from Egypt by air.

Figure 1: Conceptualisation of Factors Affecting Passenger Demand on Air Transport from/to Egypt


Factors Contributing to Egyptian Passenger Demand on International Air Transport from/to Egypt
GDP/Capita
Population in Egypt (Capita)
Egyptian Pilgrims (Haij - Omra)
Foreign Businessmen Conducting Business in Egypt
Gross Domestic Product (GDP) in Egypt
Foreign Expatriates Based in Egypt
Egyptian Immigrants
Foreign Tourists Visiting Egypt
Egyptians Working Abroad
Egyptian Tourists Visiting Other Countries
Diplomats & Officials Based in Egypt
Egyptian Businessmen Conducting Business in Other Countries
Diplomats & Officials Representing Egypt Abroad
Egyptian Graduate Students, Academics, Scholars in Exchange & Fellowship Programs
Foreign Graduate Students, Academics, Scholars in Exchange & Fellowship Programs
Demand on International Air Transport from/to Egypt (Represented by No. of International Flights or No. of Passengers Using International Flights)

## 3. FACTORS AFFECTING EGYPTAIR MARKET SHARE OF PASSENGER DEMAND ON FLIGHTS FROM/TO EGYPT

Some generic insights on the choice of air carrier, flight and fare classes were developed by Proussaloglou and Koppelman (1999). In this section, a conceptualisation of factors affecting the modal selection by passengers travelling on international flights from/to Egypt is shown in figure 2. The figure demonstrates the process involved in the selection of Egyptair versus other international carriers by travelling passengers. It is obvious that some passengers are by default Egyptair captive either due to their patriotic character, or due to Egyptian government regulations necessitating the use of the national carrier or due to monopoly of certain routes by Egyptair. On the other hand, the majority of passengers would have the choice of selecting Egyptair versus other alternative competing airlines. In this context, price and level of service related characteristics affecting the utility of

competing airlines govern passengers' mode choice. Such characteristics could include factors such as promotions, safety and security records, comfort, convenience, regularity, punctiality, schedule coverage, luggage safety, crew hospitality and friendliness, onboard entraintment facilities, designated airport facilities, etc.

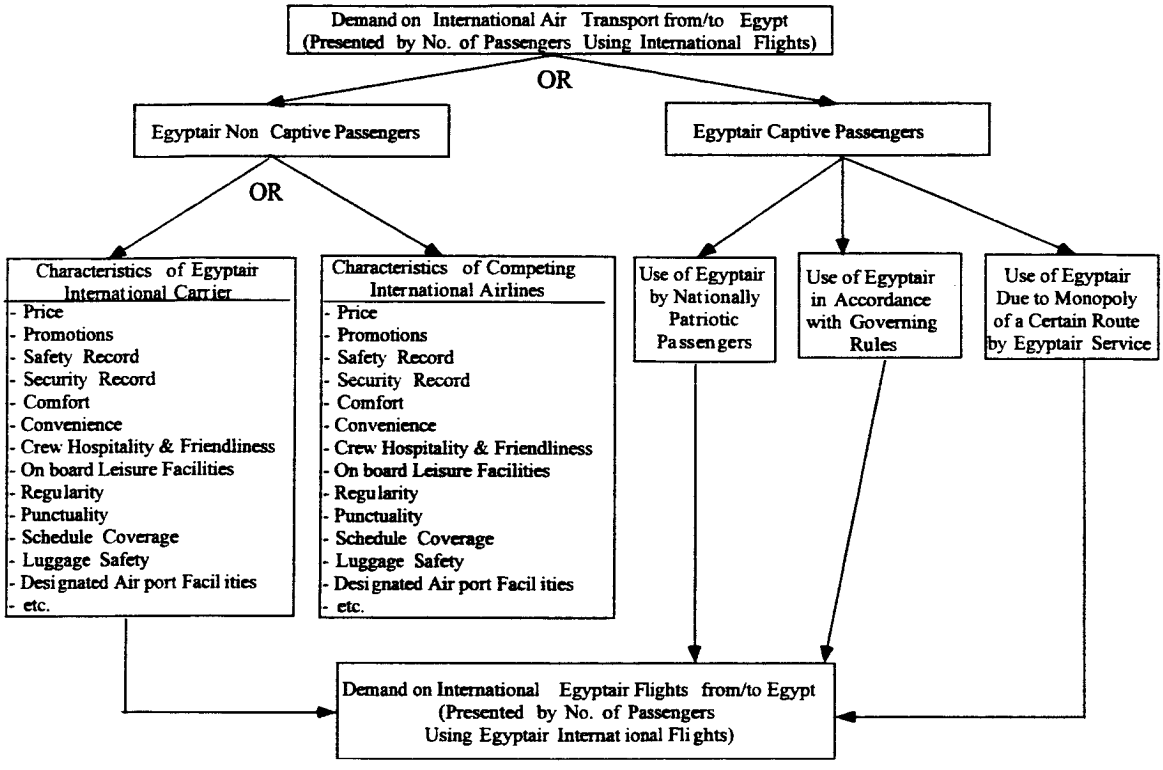


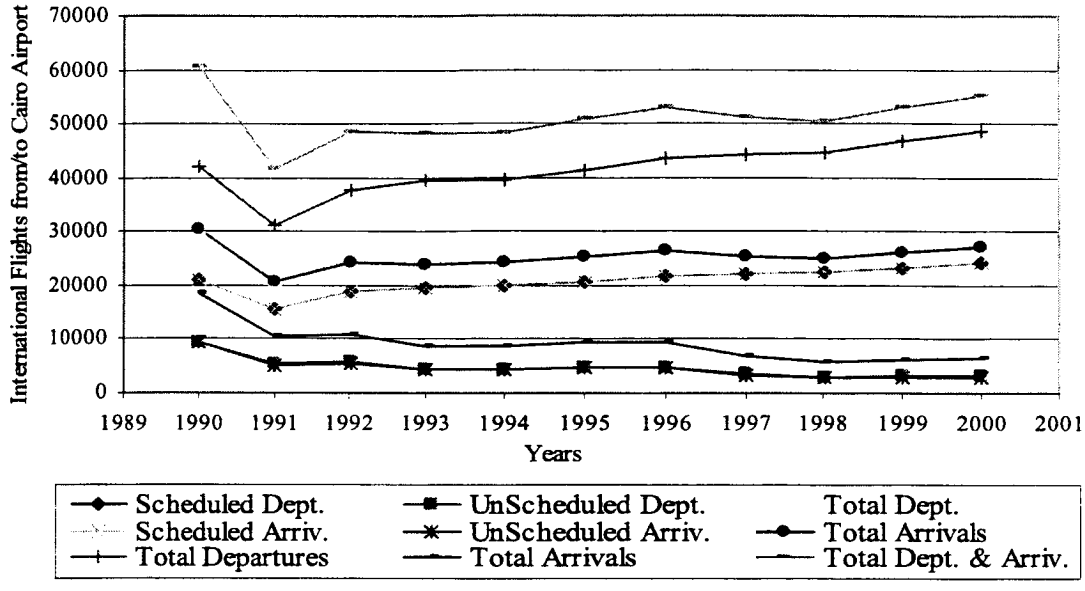

Figure 2: Conceptualisation of Factors Affecting Egyptair Market Share of Passenger Demand on International Flights from/to Egypt

## 4. DEPENDENT AND EXPLANTAORY VARIABLES FOR DEVELOPING DEMAND MODELS FOR PASSENGERS TRAVELLING FROM/TO CAIRO AIRPORT

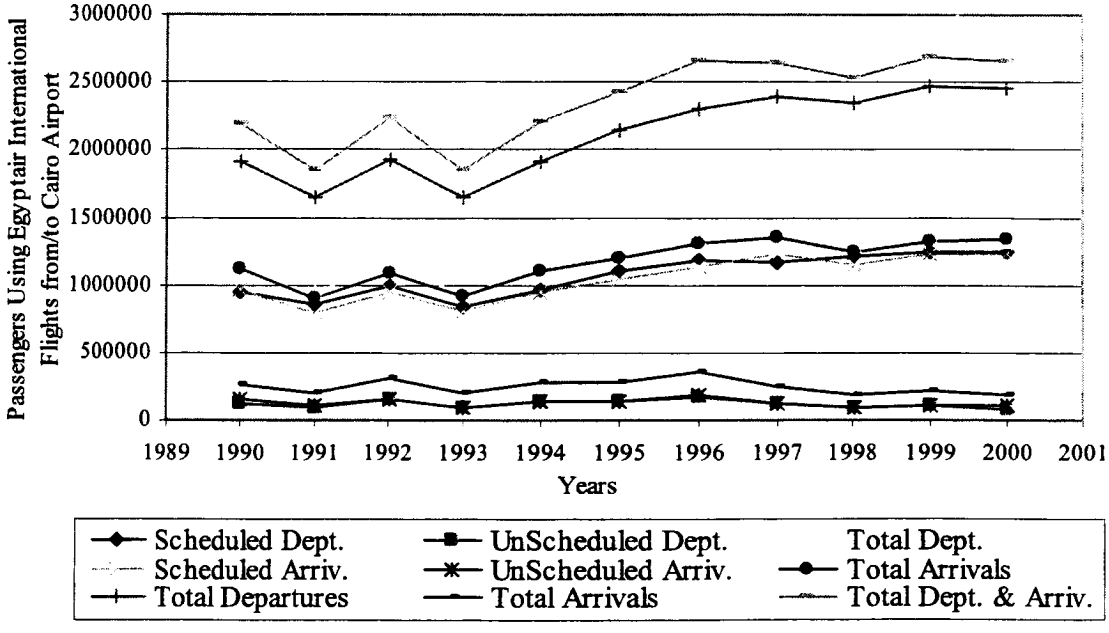
The core of the research lies in developing demand models for international flights from/to Cairo airport as well as for passengers using Egyptair international flights from/to Cairo airport. Based on the conceptualisation, depicted in figure 2, of factors affecting demand, a data collection exercise was conducted. Historical data, spanning over the 11 years 1990 to 2000, concerning aviation demand variables as well as other variables thought to affect this demand was compiled from several sources, see ECAA (2001), Egyptair (2001), NBE (2001), and IMF (2000).

In another research, a different approach was pursued in terms of developing separate models for each demand variable, see Reda, 2003.

Figure 3: Pattern of Historical Demand of International Passenger Flights from/to Cairo Airport




Figures: Pattern of Historical Demand of Passengers Using Egyptair International Flights from/to Cairo Airport



Demand variables include number of international flights (scheduled or unscheduled) as well as number of passengers using international Egyptair flights (scheduled or unscheduled) originating from or attracted to Cairo airport. Demand variables were historically plotted in an effort to determine the most proper and representative ones, see figures 3 and 4. Several observations were noted, first that demand in 1990 was relatively high, being the year just before the second Gulf war. Demand dropped significantly in 1991, due to the Gulf war and its dramatic effect on tourism and aviation sector in Egypt. In this context, it was decided to drop data points pertaining to these two years from the development of the models. The other noted observation is that generated as well as attracted demand for both scheduled and unscheduled trips are almost similar in magnitude. This demonstrates the aviation phenomenon of passengers usually using return tickets on international flights. Based on these analyses, it was decided to add total departures and arrivals of international flights from/to Cairo airport and use the sum as the dependent variable representing passenger aviation demand from/to Cairo airport. Similarly, it was decided to use total number of passengers using Egyptair international flights from/to Cairo airport as the dependent variable representing passenger aviation demand on Egyptair.

Historical data on a number of explanatory variables thought to affect demand was also compiled, namely, population, GDP, GDP/Capita, number of Egyptian Haij pilgrims, number of foreign tourists, number of Egyptians working abroad, as well as number of Egyptian immigrants. A matrix was then developed containing values of Pearson correlation coefficient and its significance in an effort to demonstrate the extent of correlation between demand variables and selected explanatory variables, see table 1. The matrix shows the collinearity between population and Haij pilgrims as well as between GDP and GDP/capita. This was expected as the number of yearly pilgrims is determined in accordance with Saudi quota being 0.001 of population of Muslim countries. In addition the matrix showed the illogical negative signs of the correlation coefficients between demand variables and number of Egyptian working abroad as well as Egyptian immigrants. Based on these analyses, it was decided to develop demand models relating demand variables to population, GDP and number of foreign tourists.

Table 1: Pearson Correlation Coefficients Between Variables Representing International Passenger Demand from/to Cairo Airport (CA) and Some Explanatory Variables

| Explanatory Variables<br><br>Air Passenger Demand | Population (Capita) | GDP* | GDP/ Capita | Egyptian Pilgrims (Haij) | Foreign Tourists | Egyptian Working Abroad | Egyptian Immigr. |
|---|---|---|---|---|---|---|---|
| Total International Flights from/to CA | 0.85 (0.004) Sig. | 0.861 (0.003) Sig. | 0.86 (0.003) Sig. | 0.85 (0.004) Sig | 0.903 (0.001) Sig. | -0.855 (0.003) Not Logical | -0.494 (0.176) Not Logical |
| Total International Passengers | 0.82 (0.007) Sig. | 0.804 (0.009) Sig. | 0.81 (0.008) Sig. | 0.82 (0.007) Sig | 0.822 (0.007) Sig. | -0.922 (0.00) Not Logical | -0.651 (0.057) Not |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Using Egyptair from/to CA | | | | | | | Logical |

GDP in Current Prices Using Local Currency i.e. Egyptian Pound (L.E.) Currently 1US$ ≅ 6 L.E.
Sig.= Significant i.e. the hypothesis $H_0$ stating that the two variables are independent is rejected.

## 5. DEVELOPING PASSENGER DEMAND MODELS FOR INTERNATIONAL AVIATION FROM/TO EGYPT

Traditionally, econometric models are utilised in the forecast of air transport demand. Recently fuzzy models, see Profillidis (2000), models based on artificial neural networks, see Alekseev and Seixas (2002), as well as models based on scenario forecasts, see Cline (1998) were developed for the air transport passenger demand forecasting. In this section selected demand and explanatory variables were utilized to calibrate two types of econometric models. The first type is single variable models, where four functional relations, namely linear, logarithmic, power and exponential functions, were tested to obtain a best fit. This was done using SPSS software, see Norusis (1999). The result of such modelling exercise is summarised and compared in table 2 as well as being detailed in figures 5 through 10. All of the calibrated models were subjected to a number of statistical tests. To establish the goodness of fit and statistical significance of the models, two statistical indicators were computed, namely the $R^2$ and the F-statistic, see table 2. It is obvious from the table that number of foreign tourists visiting Egypt represents the best fitted explanatory variable and that the power function was the best non linear function in terms of simulating the dependency of annual total international flights from/to Cairo Airport on annual number of foreign tourists. On the other hand, the table also shows that the logarithmic function was the best function in terms of simulating the dependency of total international passengers using Egyptair from/to Cairo Airport on annual number of foreign tourists.

Table 2: Single Variable Models Relating Air Passenger Demand Variables to Selected Explanatory Variables

| Explanatory Variables<br>Air Passenger Demand | Population (Capita)<br>(X) | GDP<br>(X) | Foreign Tourists<br>(X) |
|---|---|---|---|
| Total International Flights from/to Cairo Airport (Y) | $Y=26180e^{1E-08(X)}$<br>$R^2$ =0.73, F = 18.7<br>Sig. = 0.003, Sig.<br>d.f. =7 | $Y=44416e^{6E-13(X)}$<br>$R^2$ =0.74, F = 20.3<br>Sig. = 0.003, Sig.<br>d.f. =7 | $Y=5389(X)^{0.1485}$<br>$R^2$ =0.82, F = 32.7<br>Sig. = 0.001, Sig.<br>d.f. =7 |
| Total International Passengers Using Egyptair from/to Cairo Airport (Y) | Y=4E+06ln(X)-7E+07<br>$R^2$ =0.68, F = 14.8<br>Sig. = 0.006, Sig.<br>d.f. =7 | Y=774056ln(X)-2E+07<br>$R^2$ =0.68, F = 14.9<br>Sig. = 0.006, Sig.<br>d.f. =7 | Y=887533ln(X)-1E+07<br>$R^2$ =0.77, F = 22.9<br>Sig. = 0.002, Sig.<br>d.f. =7 |

The previous models have a significant limitation in terms of modelling demand as a function of a single explanatory variable. These variables are either representative of

demand generated by Egyptian nationals such as the case of population, and GDP or alternatively representative of demand generated by foreign nationals such as the case of number of foreign tourists visiting Egypt. In this context, it was felt that a multiple regression containing at least two explanatory variables, one representing demand of Egyptian nationals and the other representing demand of foreign nationals, would be more appropriate and representative. Several trials were conducted using the three selected explanatory variables as well as combination of two. The multiple regression models using three variables had less degrees of freedom and produced negative signs for some calibrated parameters. This was neither statistically nor logically accepted. On the other hand, models including population or GDP in combination with number of foreign tourists as independent variables were calibrated, see table 3. The table shows that those models with population and number of foreign tourists produced the best fit as well as proved to be the most logical and statistically significant models.

Table 3: Multiple Regression Models Relating Air Passenger Demand Variables to Selected Explanatory Variables

| Explanatory Variables Air Passenger Demand | Population ($X_1$) & Foreign Tourists ($X_2$) | GDP ($X_1$) & Foreign Tourists ($X_2$) |
|---|---|---|
| Total International Flights from/to Cairo Airport (Y) | $Y=1.0E\text{-}04(X_1)+1.7E\text{-}03(X_2)+38283$<br>$R^2=0.82$, F = 13.7<br>Sig. = 0.006, Sig.<br>d.f. = 6 (SELECTED MODEL) | $Y=6.8E\text{-}09(X_1)+1.6E\text{-}03(X_2)+43227$<br>$R^2=0.82$, F = 13.8<br>Sig. = 0.006, Sig.<br>d.f. = 6 |
| Total International Passengers Using Egyptair from/to Cairo Airport (Y) | $Y=3.3E\text{-}02(X_1)+0.119(X_2)-26680$<br>$R^2=0.71$, F = 7.2<br>Sig. = 0.026, Sig.<br>d.f. = 6 (SELECTED MODEL) | $Y=1.32E\text{-}06(X_1)+0.145(X_2)+1584746$<br>$R^2=0.69$, F = 6.7<br>Sig. = 0.03, Sig.<br>d.f. = 6 |

Figure 5: Exponential Model Relating Total International Flights from/to Cairo Airport as a Function of Population in Egypt

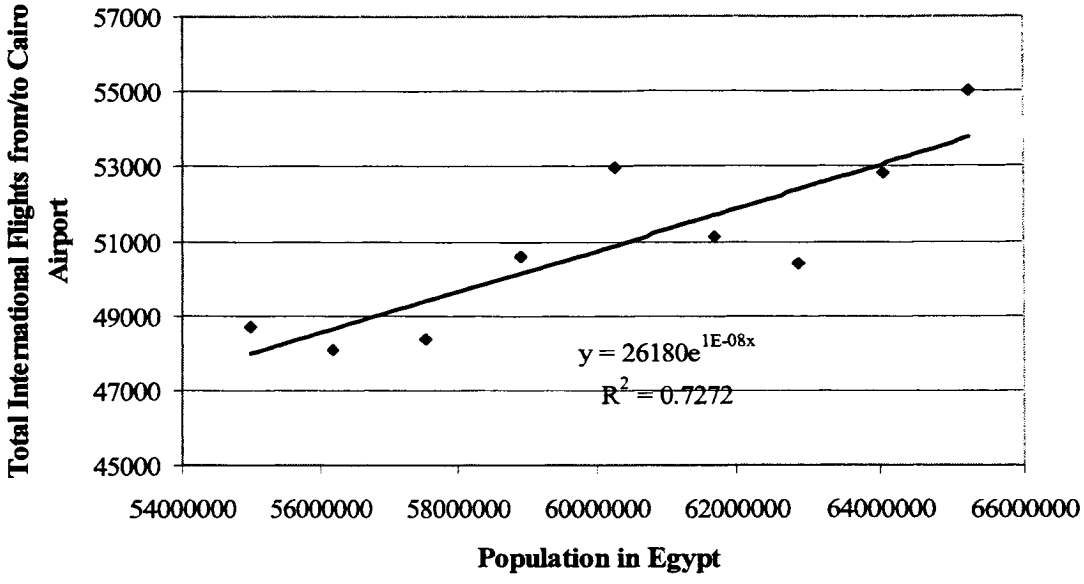



Figure 6: Exponential Model Relating Total International Flights from/to Cairo Airport as a Function of Gross Domestic Product in Egypt

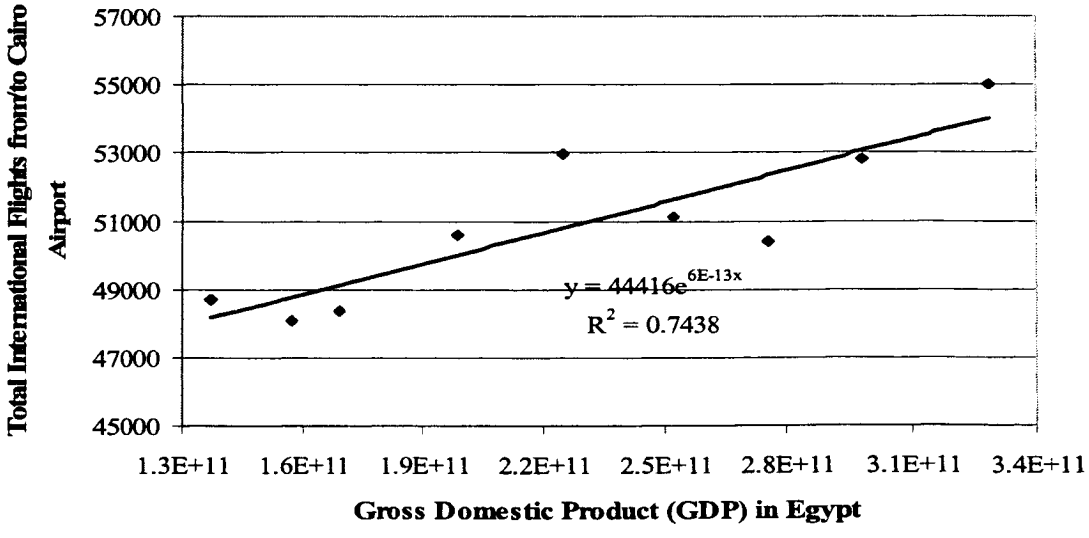


Figure 7: Power Model Relating Total International Flights from/to Cairo Airport as a Function of Number of Tourists Visiting Egypt

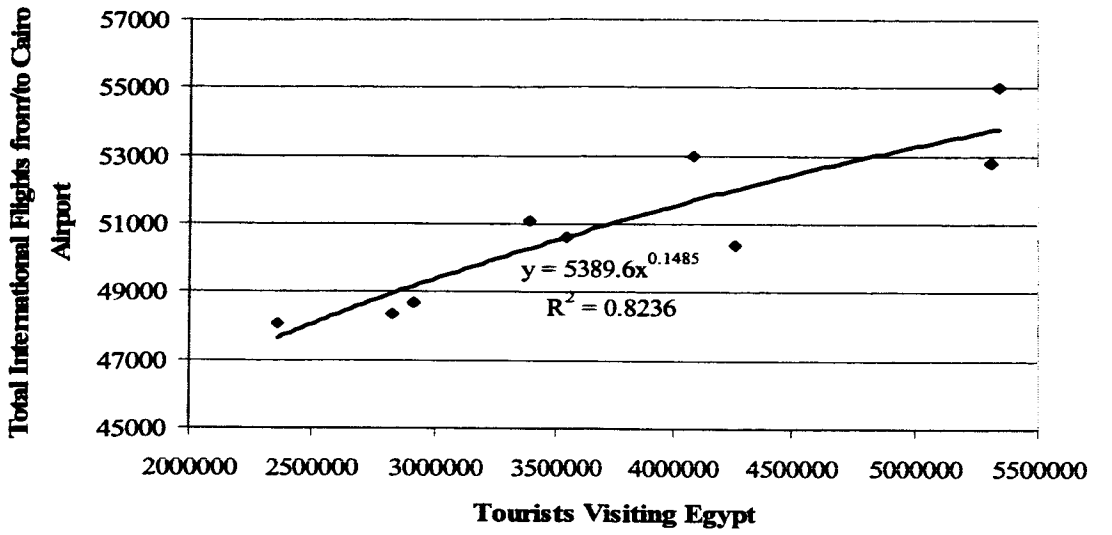



Figure 8: Logarithmic Model Relating Total Passengers Using Egyptair International Flights from/to Cairo Airport as a Function of Population in Egypt

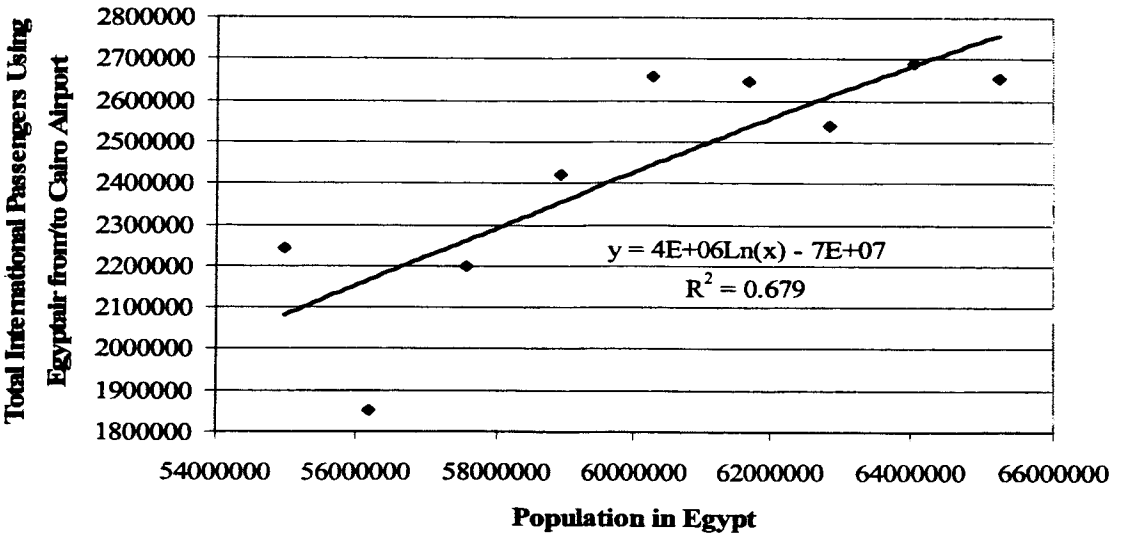


Figure 9: Logarithmic Model Relating Total Passengers Using Egyptair International Flights from/to Cairo Airport as a Function of Gross Domestic Product in Egypt

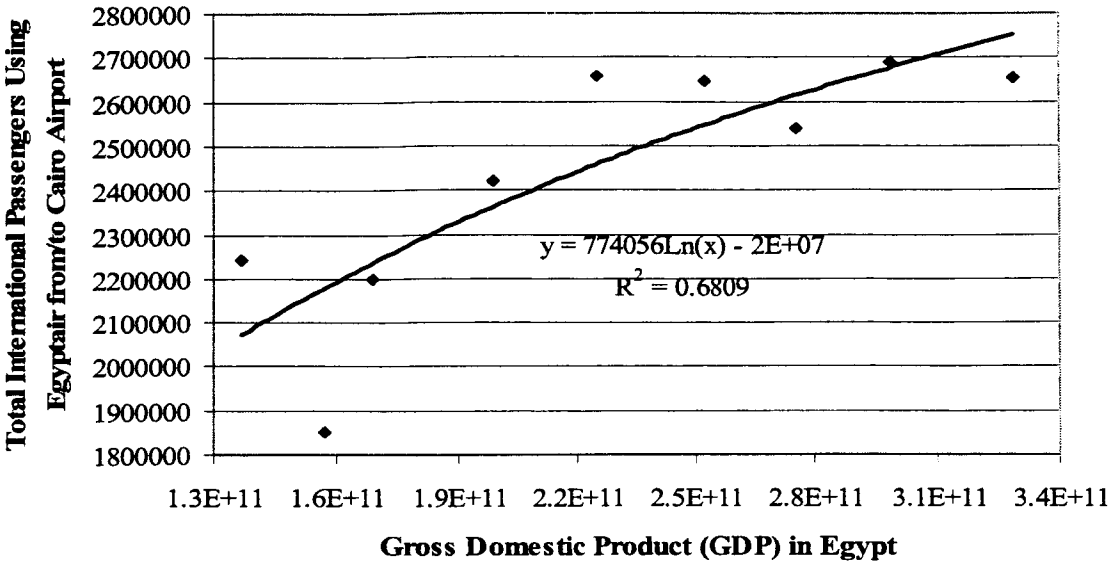
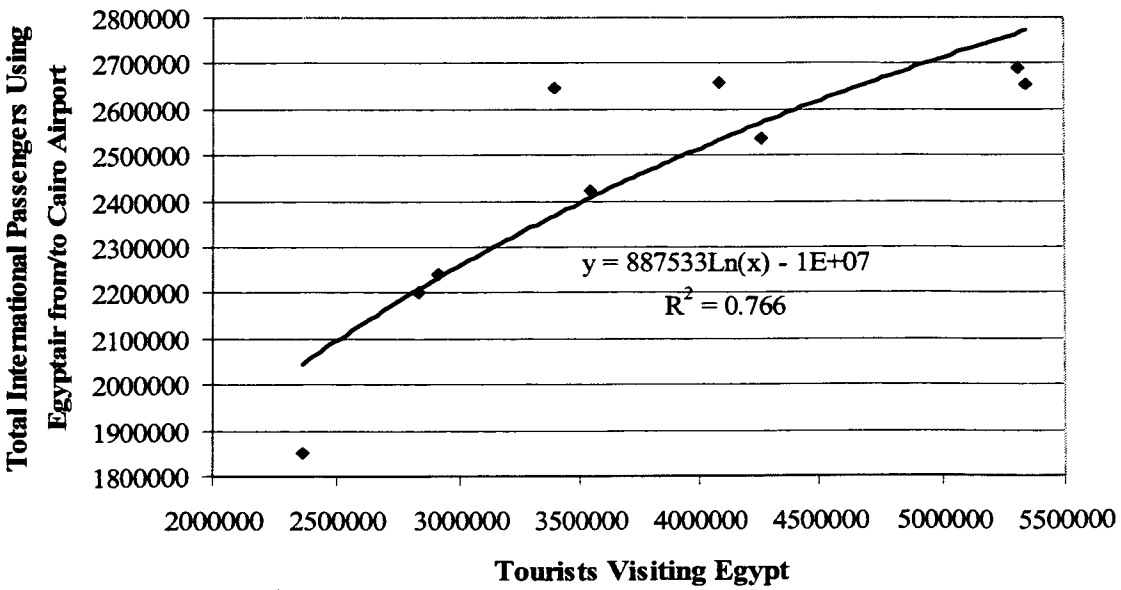



Figure 10: Logarithmic Model Relating Total Passengers Using Egyptair International Flights from/to Cairo Airport as a Function of Number of Tourists Visiting Egypt



## 6. APPLICABILITY OF DEVELOPED MODELS IN FORECASTING FUTURE DEMAND

In this section, the two selected models will be used to perform a short term forecasting of expected demand in terms of number of international flights as well as number of passengers using Egyptair international flights. In order to carry out such forecasts, expected future values for explanatory variables should be first obtained. In this context, two time series models were developed to simulate the changes in population in Egypt as well as in number of foreign tourists visiting Egypt with respect to time. The population model was based on an 11 points data set spanning from 1990 to 2000, while the tourists model was based on a 9 points data set spanning from 1992 to 2000. It was assumed that the second Gulf crisis did not affect the population growth but definitely affected the pattern for number of tourists visiting Egypt and that was the reason for ignoring the 1990 and 1991 data points for the tourists model. The two models took the exponential form as follows:

$$\text{Population in Egypt} = 5E{+}07 * e^{0.0219(\text{Years})} \quad \text{with 1990 as the base year}$$

$$\text{Foreign Tourists Visiting Egypt} = 2E{+}06 * e^{0.0939(\text{Years})} \quad \text{with 1992 as the base year}$$

The above models were used to forecast expected population and number of foreign tourists in 2004 and 2005. These forecasts are shown in table 4. These forecasts were then fed into the selected models displayed in table 3 and forecasts of passenger aviation demand represented by number of international flights as well as number of passengers using Egyptair were obtained, see table 4. These were averaged from annual into daily forecasts and further more into arrivals and departures, see table 4.

Table 4: Applicability of Developed Models in Forecasting Future Passenger Aviation Demand from/to Cairo Airport

| Forecasting Years / Forecasts | 2004 | 2005 |
|---|---|---|
| Population in Egypt | 69444162 | 70981764 |
| Foreign Tourists Visiting Egypt | 6779119 | 7446523 |
| Total International Flights from/to Cairo Airport (Annually) | 56752 | 58040 |
| Passengers Using Egyptair International Flights from/to Cairo Airport (Annually) | 3071693 | 3201854 |
| Total International Flights from/to Cairo Airport (Daily) | 156 | 159 |
| Passengers Using Egyptair International Flights from/to Cairo Airport (Daily) | 8416 | 8772 |
| Total International Flights from Cairo Airport (Daily Departures) | 78 | 80 |
| Total International Flights to Cairo Airport (Daily Arrivals) | 78 | 80 |
| Passengers Using Egyptair International Flights from Cairo Airport (Daily Departures) | 4208 | 4386 |
| Passengers Using Egyptair International Flights to Cairo Airport (Daily Arrivals) | 4208 | 4386 |

The usefulness of such forecasts lies in their potential utilisation in resource planning in terms of airport capacity and sufficiency of resources as well as in terms of fleet purchase by Egyptair. Such demand forecasts can be also used as input into Cairo airport and Egyptair cost and revenue models.

## 7. CONCLUSIONS

The main aim of this research was to develop demand models for passenger aviation from/to Cairo airport. In pursuing this objective the research developed two conceptual frameworks, the first pertaining to factors affecting the passenger aviation demand to/from Egypt, while the second was related with factors influencing the selection of Egyptair as a potential international carrier by passengers. Historical data spanning over 11 years from 1990 to 2000 representing demand as well as other explanatory variables were collected, and compiled from several sources. These were plotted and correlated in an effort to determine which are the most representative, appropriate and suitable data points and variables to be included in models' development. Data points for the two years 1990 and 1991 were ignored due to the effect of the second Gulf crisis. Two demand variables were selected, namely total international flights from/to Cairo airport as well as total number of passengers using Egyptair international flights from/to Cairo airport. In addition, two explanatory variables were also selected to represent demand of Egyptian nationals i.e. population and GDP as well as one variable selected to represent demand of foreign nationals i.e. number of foreign tourists visiting Egypt. These variables were then used to develop several single and multiple variable models with different functional forms.

Finally two models were selected based on their logical acceptability, best fit and statistical significance. In an effort to demonstrate the applicability and practicality of the developed models, these were utilised to forecast future expected passenger aviation demand from/to Cairo airport. The usefulness of such forecasts lies in their utilisation in resource planning in terms of airport capacity and sufficiency of resources as well as in terms of fleet purchase by Egyptair. Such demand forecasts can be also used as input into Cairo airport and Egyptair cost and revenue models.

In conducting this research several issues were revealed. These will form the basis for further future research. First, several factors identified as affecting demand were not considered in the models' development due to unavailability of data. Second, the developed models are representative of Cairo airport only. Despite that Cairo international airport is the major and most dominant airport in Egypt, however other airports do exist and are currently playing important roles. For example Hurgadah airport is currently attracting direct charter flights transporting foreign tourists. In this context, the developed models should be expanded to include distribution factors of potential demand to/from other airports in Egypt. As a matter of fact a national plan for developing an integrated airport system ought to be pursued. Such direction can be guided by efforts conducted by other countries such as UK, see DETR (2000) and USA, see USDOT (1999) & (2000). Third, no mode choice models were developed to simulate the process involved in selection of

Egyptair versus other international carriers. In this context, with the availability of data, binary and multinomial logit models could be developed. Fourth, and in accordance with the viewpoint of Graham (1999), the effects of deregulation and institutional reform have to be considered in air passenger demand forecasting.

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